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ABSTRACT

Success in the rapid commercialization of technology has changed over the years as competition from foreign countries has increased. The United States has been slow to respond to the changing nature of the technological competition. This report focuses on the role of the federal government in facilitating and removing impediments to the commercial application of technology. Issues discussed include: (1) foreign competition; (2) the commercialization problem; (3) the fragmented public policy environment; (4) the new developments in U.S. technology policy; and (5) the regulatory and macroeconomic framework. A number of findings and recommendations are presented. (CW)

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COUNCIL
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PICKING UP THE PACE:

THE COMMERCIAL CHALLENGE TO AMERICAN INNOVATION

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PREFACE

In field after field — from combustion engineering to consumer electronics, from machine tools to the integrated circuit — foreign competitors have moved into markets pioneered and once dominated by American firms. By aggressively developing and commercializing new technologies, foreign companies have achieved considerable economic success, sometimes taking over entire industries. Often, their success was built on exploiting inventions made in American laboratories by American scientists.

Throughout the 1970s, as trade deficits in U.S. "smokestack" industries mounted, we comforted ourselves with the notion that foreign commercial successes did not really matter since the economic future lay with "sunrise" high-technology industries. In 1986, however, we suffered our first high-technology trade deficit; and in 1987, despite the decline of the dollar, we registered only a modest high-tech trade surplus.

Then, we told ourselves that while other nations might be able to take advantage of lower wages and an overvalued dollar to make and sell products more cheaply, those countries were incapable of innovation themselves. Today, about half of all the patents awarded in the United States go to foreign inventors, and an increasing percentage of these patents are the important ones, the ones often cited in subsequent research applications.

We cannot afford any further erosion in our once-commanding technological lead. In the race for economic prosperity, the commercial application of technology is the nation's "value-added" — the process by which America's vaunted know-how is taken from the laboratory to the marketplace. Because technology is a driving force behind productivity improvements, export strength and a high standard of living, the stakes are enormous.

In examining the commercial challenge to American innovation, we ask one basic question: How can the federal government create an environment that is more conducive to the rapid commercialization of technology by the private sector? We believe that facilitating U.S. private sector efforts to move ideas from the laboratory to the marketplace should be a top national priority. America's future competitiveness and standard of living depend on it.

The Council on Competitiveness recognizes that the private sector has the primary responsibility for commercializing technology. It alone can develop, produce and market new products and processes. In this report, however, we focus on the government's role for two reasons. First, public policies undeniably create the climate in which American scientists, engineers, manufacturers and managers work. Second, and more important, the federal government is in a position to create public awareness of technology's central role in revitalizing American competitiveness and to promote the cooperation necessary to turn that awareness into national action.

The primary challenge for policy-makers is to develop a new public policy framework for technology that is appropriate for today's global competitive environment. While other governments have used science and technology policies to promote industrial growth, commercial spin-offs from U.S. government programs, if they occurred at all, have been incidental. Because the ability of American firms to identify, develop and commercialize technology is critical to our ability to compete in world markets, it is essential for the government to promote these private sector efforts systematically. Our report recommends a series of improvements.

In developing a framework for action, both the public and private sectors should be guided by a new understanding of the innovation process. Part of the reason for the erosion of America's technological lead is that we have tended to view progress in science and technology as a relay race, a step-by-step process whereby the "basic research runner" handed the baton to the "applied research runner," who handed off to the development and marketing specialists, and so on. Many of our efforts in the past few decades have concentrated on ensuring that the first runner — the basic researcher — exploded out of the blocks with a breakthrough invention that provided enough of a cushion for the rest of the team to coast to victory.

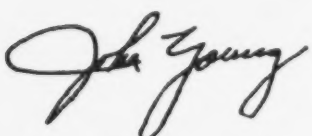
The innovation game, however, has changed. Instead of a relay race, research and development require a total team effort — where individual heroics are subordinated to a coordinated team

approach, where systematic long-term progress is more important than a fast start out of the blocks. In many ways, foreign competitors are the driving force behind this new approach to innovation; and in many instances they have capitalized on it ahead of U.S. companies and the federal government. Because the approach to technology has changed, so must public policy.

The Council believes that the United States continues to maintain an overall world lead in science and technology. Our concern is the erosion of that lead. In pursuing a new level of scientific and technological excellence, America brings many strengths: a superb foundation of scientific expertise; a university system that is the envy of the world; a heritage of entrepreneurship; a flexible form of government that can correct policies as circumstances change; and the renowned willingness of the American people and their public officials to rise to a challenge.

Four decades ago, America restructured its technology and science policies in response to the challenge of the post-war setting and entered an era of unparalleled scientific achievement. Today, spurred by the commercial gains of foreign competitors, America must respond again. Increased government attention to, and support for, the commercialization of technology is a vital part of that response.

Thus, the recommendations contained in this report are offered not as a final answer, but as a necessary beginning in the long process of rebuilding American competitiveness.



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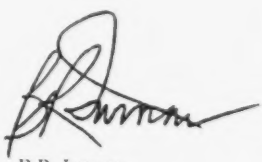

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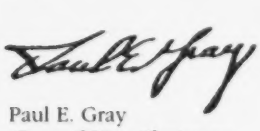

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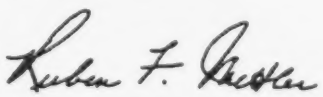

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EXECUTIVE SUMMARY

Foreign success in the rapid commercialization of technology is changing the way R&D and the innovation process are viewed. When the United States was primarily a domestic marketplace, the pace at which technology was turned into new products and processes was only one of several factors that determined commercial success. Today, with companies from around the world vying to gain competitive advantage from technology, time is a crucial consideration. The speed with which firms are able to translate innovations into commercial products and processes often spells the difference between success and failure.

Countries without a large scientific base have made up for shortcomings in research by concentrating industrial resources on the rapid commercial application of new ideas. By developing superior manufacturing systems, emphasizing quality and creating a supportive financial structure, other nations have been able to take new discoveries, often American in origin, and quickly move them into the marketplace. Government policies have supported this effort.

The United States, long used to preeminence in basic research, has been slow to recognize the changing nature of technological competition. As the nation wakes up to this new reality, it must reassess the roles played by all sectors — industry, academia, labor and government. The American economic system is based on the premise that the primary responsibility for commercialization belongs with the private sector. But success ultimately depends on a team effort. University research often sets the stage for private sector advances; a skilled, motivated labor force is essential to sustained progress; and government policies create the economic environment in which firms must operate.

This report focuses on the role of the federal government in facilitating and removing impediments to the commercial application of technology. It addresses several questions: How has international competition affected technology and the innovation process? What are the warning signals of a problem? Does federal policy facilitate the accelerated development of commercial technology? Is the technology that is developed by federal funding worthwhile and available in a timely way to the American private sector for commercialization? Does the regulatory and macroeconomic framework provide adequate support or does it hinder commercial activities?

The findings listed below address these questions and summarize the key points in the report. In doing so, they set the stage for the recommendations that follow.

Summary of Findings

The effective development and deployment of technology is critical to America's ability to compete in world markets. Technology has traditionally been a major U.S. export strength, and leading economists estimate that technology is responsible for as much as 80 percent of U.S. productivity growth since the Depression. In today's international economy, virtually all aspects of the commercialization process have become globalized. For U.S. companies, this means that they must become as much "hunters and gatherers" of technology as they are generators; for the federal government, it means that public policy must take into account the impact of international competition on the commercial application of technology.

Technological innovation is closely linked to systematic, incremental improvements that are driven by market needs. America's post-war preeminence resulted largely from the "research-driven" model of the innovative process. This model views innovation as a linear process—starting with a major scientific breakthrough, progressing through design, development and production, and ending with marketplace distribution. Consequently, this model emphasizes the importance of basic research. The research-based model must be supplemented by another view that focuses more on market-driven applications of technology. The new model suggests that innovation is better described as an interactive or reiterative interdependent process in which design, manufacturing and product development all drive research and, at the same time, are highly dependent on research. This approach involves systematic, incremental improvements in products and processes as firms react to ever-changing market signals

A variety of warning signals point to problems in the U.S. ability to commercialize technology rapidly. The signals of the commercialization problem are diverse. America registered its first high-tech trade deficit in 1986. The U.S. share of the consumer electronics market has dipped from about 100 percent in 1970 to less than 5 percent today. Other core industries — from semiconductors to pharmaceuticals — are being strongly challenged by foreign competitors. Foreign inventors captured 46.6 percent of U.S. patents in 1987 (up from 35 percent in 1975); and the Japanese hold the key patents in an increasing number of fields.

Many of America's problems stem from not rapidly moving new innovations into the marketplace and from underestimating the importance of manufacturing, quality and long-term planning. When the United States so thoroughly dominated the world economy, the speedy translation of new ideas into practical products and processes was not a crucial factor in commercial success. International competition has changed that situation. For technology-based industry, a failure to focus on the rapid application of new ideas can be devastating. Science and technology thrive in organizations where there is a critical mass of highly skilled talent, adequate facilities and equipment, as well as a sense of mission. Long-term investments in research, constant improvements in manufacturing processes, attention to quality, a supportive financial environment and the creation of a skilled, motivated work force are essential ingredients to success.

The federal government has not focused on the commercial application of technology as a public policy issue. As a result, current government policies and procedures tend to inhibit rather than accelerate rapid commercialization. In many ways, America's hands are tied by policies geared to another era that do not address today's competitive realities. Since the end of World War II, U.S. government science and technology programs have been dominated by two overriding concerns: basic research and support for specific national missions, such as national security and health. Largely as a result of this concentrated federal effort, American science has enjoyed an era of unprecedented excellence. In staking out a forceful role in the advancement of science, however, the federal government has tended to ignore factors important to the commercialization of technology. U.S. public officials too readily assumed that preeminence in science automatically confers technological and commercial success as well. It does not — at least since the rapid gains made by other nations. America assumed that government support for science would be adequate to provide for technology. It is not. Existing federal science and technology programs do not adequately recognize the new market-driven model of innovation.

Large federal budget deficits in a low savings society drive up the cost of capital and hinder the commercialization of technology. The commercial application of technology involves significant short-term investments in R&D that are rewarded only over the long-term. As a result, the cost and supply of capital are critical considerations. The combination of large U.S. federal budget deficits and low U.S. savings drive up the cost of capital in the United States. Consequently, U.S. firms are at a disadvantage in the race to commercialize technology. Large budget deficits and low savings also present America with another dilemma: either it can forego investment, which would hobble technological innovation, or borrow capital from abroad, which increases the U.S. foreign debt.

Federal government mechanisms for determining science and technology priorities and for coordinating policies across agencies are insufficient. No line agency of the federal government has broad responsibility for research and other activities related to civilian technology or for the coordination of technology policy at the national level. In the Executive Branch, responsibility for R&D is dispersed among 12 agencies; in Congress, the civilian science budget alone is divided among 9 of 13 different appropriations subcommittees. There is little federal focus on technology's impact on the economy, and there is no mechanism for setting overall priorities. Individual agencies are responsible only for their particular missions. The one organization that provides an overview of federal research and other activities related to economic performance — the White House Office

of Science and Technology Policy — has no line functions and a small budget, with staff mostly on temporary loan from other agencies.

Federal investments in education, facilities and equipment that make up the nation's science and technology infrastructure are inadequate. American students consistently score lower on international math and science tests than their counterparts in other industrial nations; 1,300 to 1,800 engineering faculty positions at U.S. colleges and universities are currently vacant; the nation faces a projected shortfall of over 500,000 scientists and engineers by the year 2010; and federal funding of university research facilities has dropped by 95 percent in real terms over the past two decades. The federal government has a vital role to play in addressing these problems.

Inconsistent government R&D incentives undermine private sector efforts to make long-term investments in R&D. R&D is a long-term proposition for industry, but government R&D incentives can change from year-to-year, thereby undermining industry's ability to plan ahead. The R&D Tax Credit, the moratorium on implementation of Treasury Regulation 1.861-8 and the Basic Research Tax Credit are among the important R&D incentives for industry that have not been applied consistently over the long-run.

There is no consensus on the scope, mission and relevance of the federal laboratories to the needs of the country over the next 20 years. The federal government operates more than 700 laboratories whose annual budget of approximately $20 billion is equal to almost one-third of the government's annual R&D expenditures and one-sixth of the nation's total. The technology needs of industry are not among their major priorities. It is difficult to determine exactly how many laboratories there are and how many scientists and engineers they employ, much less which labs are effective in meeting their objectives and which should be closed down or reorganized for other purposes. Although recent efforts to promote technology transfer from the federal labs to the U.S. private sector are a step in the right direction, these broader issues also need to be addressed.

In serving as a contractor and regulator of economic activity, the federal government has too often assumed an adversarial role in its relationship with industry. To commercialize new technologies, U.S. industry must overcome a set of economic, legal and regulatory barriers, such as inadequate protection of intellectual property, restrictions on research, pre-market approval of certain pharmaceuticals and chemicals, excessive export-licensing rules and unpredictable state product-liability laws. Most laws and regulations were enacted to address justifiable social concerns that have little to do with technology. Nonetheless, their aggregate impact on the commercial application of technology is enormous. This impact is often unforeseen by lawmakers, ignored by enforcement officials and almost entirely unmanaged.

In too many instances, promising science and technology initiatives have not been implemented. During the 1980s, the federal government took a number of steps to promote technology. In many respects, these efforts focused on the right issues: cooperative R&D, technology transfer, intellectual property rights, regulatory constraints, generic manufacturing and government organization. All too often, however, these policies were piecemeal, *ad hoc* and inconsistent. Implementation has been a recurrent problem. In some cases, promising new laws were enacted, but never funded. In others, bureaucrats could not accommodate new priorities rapidly, and a shortage of skilled staff slowed progress. In still others, political considerations came into play. An initiative enacted by one Congress — the R&D tax credit, for instance — was undercut by the next. Throughout the government, there is far too little coordination within the federal bureaucracy and among the federal agencies, the states and private sector.

State governments have established an extensive network of technology programs that has yielded several important lessons. By mid-1987, 31 states had offices responsible for promoting the growth of technology-based businesses, and most other states provided assistance through state university systems or economic development authorities. State technology programs cannot provide a quick fix to the commercialization problem, but

they do hold some important lessons. Among them are the following: 1) infrastructure, not projects, is usually viewed as the priority ingredient for success; 2) the private sector must take the lead; 3) a broad range of activities, from research to business-plan development, are necessary; and 4) innovation is a pragmatic, non-doctrinaire activity that cannot be reduced to a single model or approach.

Summary of Recommendations

To be effective, government actions to foster the commercial application of technology must respond to the needs of the private sector. In determining what kind of role the government should play, it is important to ask the question, "What does the private sector need to commercialize technology more effectively, and how can the government help meet these needs?" Viewed from this perspective, it is clear that government reform should center on four areas: 1) macroeconomic policy; 2) science and technology policy-making machinery; 3) infrastructure; and 4) expanded national R&D efforts. The recommendations below address the key policy issues in each area.

RECOMMENDATION 1: THE FEDERAL GOVERNMENT SHOULD IMPROVE THE MACROECONOMIC ENVIRONMENT THAT AFFECTS THE PRIVATE SECTOR'S ABILITY TO DEVELOP AND APPLY TECHNOLOGY.

Make fiscal policy more supportive of private sector efforts to commercialize technology. U.S. fiscal policy — including large federal budget deficits and the tax structure — affects the supply and cost of capital to American industry, which has an important impact on private sector efforts to commercialize new technology. Credible multi-year deficit reduction should be a top priority of the new President and Congress. Furthermore, tax policy should be structured to promote savings and long-term investment. (The Council is addressing these issues more fully in a separate report to be published later in 1988.)

Strengthen U.S. trade policy for technology. The U.S. government should continue its efforts to open foreign high-technology markets, using all the tools available to it under current law. It also should attempt — both bilaterally and multilaterally — to improve protection of intellectual property abroad. The creation of a new unit for Technology, Intellectual Property, Services and Investment within the U.S. Trade Representative's Office is a step in the right direction.

RECOMMENDATION 2: THE FEDERAL GOVERNMENT SHOULD IMPROVE THE MACHINERY FOR MAKING TECHNOLOGY POLICY.

Appoint an Assistant to the President for Science and Technology. The next President should elevate the National Science Adviser to the position of Assistant to the President for Science and Technology. The Assistant to the President should report directly to the President, have Cabinet-level status and be an active member of interagency policy groups, such as the Economic Policy Council and National Security Council. Like the National Science Adviser, the Assistant to the President also would head the Office of Science and Technology Policy. Elevation of this position would not entail the creation of a new agency. The Assistant to the President should be provided with the necessary staff and resources to carry out his responsibilities, which are further described below:

- **Be a vital participant in shaping the macroeconomic and regulatory policy framework that affects the commercialization of technology.** The Assistant to the President should make sure that technology issues are carefully considered in determining broader economic policy, rather than treated as residual or secondary concerns.

- **Develop priorities and coordinate science and technology policy across agencies.** The Assistant to the President should help develop overall priorities and take them to the President for approval. He also should coordinate science and technology policy. This effort should include a review of the programs and objectives of individual science and technology agencies to ensure that they are consistent with one another and that they facilitate the commercial application of technology.

- **Review the federal science and technology budget with the Office of Management and Budget.** Nowhere in the federal budget-making process is there an evaluation of the total federal science and technology budget and its rationale in terms of national goals. The Assistant to the President should be responsible for a cross-cutting review of the overall science and technology budget, looking beyond individual agencies' missions to consider whether the aggregate budget contributes to U.S. competitiveness.

- **Monitor implementation of policy.** Much of the legislation necessary for a more effective government focus on technology is already on the books, but has not been effectively implemented. The Assistant to the President should monitor the efforts of government departments to implement these policies and bring to the President's attention failures of implementation. The Assistant to the President should work with Executive Branch agencies and Congress to make sure that key initiatives are fully implemented.

- **Work with the Office of Management and Budget's Office of Information and Regulatory Affairs.** The Assistant to the President should work closely with this office to ensure that the current regulatory framework, to the maximum extent possible, supports private sector efforts to commercialize technology. Among the issues that should be reviewed to assess their impact on the commercialization process are: export controls; procurement and reimbursement policies; standards and testing requirements; product- and plant-approval processes; reassessment of laws and regulations that hinder or slow the commercialization of technology; and ownership of data rights.

- **Develop a four-year President's strategy for science and technology.** The Assistant to the President should work with the President, Congress, relevant Executive Branch agencies and leaders from the private sector to develop an overall Administration strategy for science and technology. This strategy should be developed early in the new Administration's first year in office. It should be presented to the relevant committees in the House and Senate and made available to the American public. It should outline the Administration's objectives and detail how individual programs fit into the overall strategy. It should be updated as necessary during the Administration's term in office.

- **Forum for considering industrial technology needs.** The Assistant to the President should provide a forum where industry can discuss issues related to the commercialization of technology and international competition. Such a forum could take several forms, such as an advisory committee, an *ad hoc* group or a special ombudsman. The precise form is secondary to the primary goal of creating a forum where industry can present its views to government on technology as it relates to international competition.

Rationalize the involvement of Congress in technology-related issues. The fragmented policy apparatus for science and technology extends to Congress. Progress in the Executive Branch will have a limited impact unless it is supported by Congress. Three major issues deserve consideration: bringing technology to the macroeconomic policy table; setting priorities; and developing two-year funding for R&D.

- **Consideration of technology issues in the formulation of macroeconomic policy.** The commercial application of technology is not a discrete issue, but an integral part of broader macroeconomic policy. Fiscal policy, savings rates, investment patterns and the cost of capital all have an important impact on the commercialization process. At present, technology issues are not adequately considered during critical policy junctures. Congress needs to pay more attention to these issues in the formulation of U.S. macroeconomic policy.

- **Setting R&D funding priorities.** The Senate and House Budget Committees, in addition to setting overall funding priorities for various departments, should also review the entire federal R&D budget and outline R&D budget priorities. Such a review would refocus discussion of the

R&D budget away from the needs of individual agencies toward the needs of the nation as a whole.

- **Two-year funding for R&D.** The President and Congress should work on a process whereby both budget authorizations and appropriations for R&D apply for two years. This framework should be implemented by a two-year budget resolution, with the resulting allocations to the other congressional committees also binding for two years. To guarantee budgetary discipline, an enforcement mechanism should be established to make sure that the two-year appropriations are within the limits established during biannual presidential-congressional negotiations.

Make R&D tax provisions consistent. Inconsistencies in R&D tax provisions undermine industry's ability to plan for the long-term. In particular, the R&D tax credit should be made permanent and reviewed after 10 years to assess its impact on private sector R&D investments. A permanent moratorium should be placed on the implementation of Treasury Regulation 1.861-8, which would otherwise drive research abroad.

Increase funding for government agencies that contribute to the commercial application of technology. The budget of the National Science Foundation, which was $1.7 billion last year, should be increased systematically to meet the President's FY 1988 goal of doubling the budget over five years. In addition, systematic increases should be sought for the National Bureau of Standards, which is the primary federal laboratory with an explicit mission to aid U.S. industry, so that its budget is increased substantially over the current level.

Create a legal and regulatory environment more conducive to the commercial application of technology. The current legal and regulatory environment does not adequately take into account the need to facilitate private sector efforts to commercialize technology rapidly. Three issues stand out: some, but not all, regulations are overly stringent; approval of new products and determination of standards are not handled expeditiously; and some laws and regulations lack a rational basis. To address these issues, regulatory agencies should make competitiveness an integral consideration in implementing their missions. As part of this effort, better mechanisms should be developed to analyze and coordinate the impact of regulation on the commercial application of technology.

RECOMMENDATION 3: THE FEDERAL GOVERNMENT SHOULD INCREASE ITS INVESTMENT IN THE EDUCATION, FACILITIES AND EQUIPMENT THAT CONSTITUTE THE NATION'S TECHNOLOGY INFRASTRUCTURE.

Make education, equipment and facilities a priority investment. Competing claims, from both inside and outside the scientific community, for scarce federal dollars have complicated the science and technology budget debate. In sorting out these funding issues, Congress and the Administration should view investments in two areas as top priorities: science and engineering education; and equipment and facilities. Whenever possible, the United States should seek to work with other nations on "mega-projects" in specific technical areas related to basic research.

Initiate a faculty-development program for science and engineering. There are an estimated 1,300-1,800 vacant engineering faculty positions in U.S. universities and colleges. There are also shortages of qualified science faculty. These shortages will increase in the early 1990s as faculty trained during the 1950s start to retire. In order to meet this shortage, the federal government should launch a major faculty-development program in science and engineering. Such a program should provide grants and loans to American citizens and permanent U.S. residents sincerely interested in teaching careers to enable them to pursue graduate-level studies. These loans could then be forgiven after three years of teaching. This program would build on existing programs in the private sector, and could be extended to science and mathematics teachers in elementary and secondary schools.

Modernize university research facilities. Over the past 20 years, federal funding for university research facilities and equipment has declined by 95 percent in real terms. A 1986 White House Science Council study estimated that a $10 billion

program over the next 10 years is required to restore U.S. university research facilities to an adequate level. The Council supports passage of legislation that would begin to provide the necessary funds.

RECOMMENDATION 4: THE FEDERAL GOVERNMENT SHOULD WIDEN THE FOCUS OF NATIONAL RESEARCH AND DEVELOPMENT EFFORTS.

Re-evaluate the agenda and purpose of the federal laboratories and their relationship with industry. There is no consensus on the scope, mission and relevance of the federal laboratories to the needs of the nation over the next 20 years. Their role and utility should be thoroughly re-examined. Although the Council has not undertaken such an examination, much of U.S. industry agrees that the laboratories need to be streamlined: some need to be consolidated and others need to be closed. At a minimum, technology transfer should be elevated to an important objective of the labs and should be viewed as an important criterion in evaluating lab performance. The exchange of technical personnel between the labs and industry should be encouraged as part of this effort.

Facilitate cooperative generic manufacturing technology. The government should continue to facilitate cooperative R&D among industry, universities and government. This framework is effective for generating concentrated long-term funding and an excellent pool of talent. It remains uncertain, however, whether a significant number of participating companies will make speedy use of the results. Thus, priority consideration in establishing cooperative generic manufacturing R&D efforts should be the active participation of industry, a focus on base-building technologies and processes rather than products, and the rapid transfer of new knowledge from laboratory to marketplace. Such efforts as Sematech and the National Center for Manufacturing Sciences recognize that the private and public sectors must find new ways of working together if American industry is to respond to the reality of global competition. These efforts should be evaluated carefully to assess how best to structure joint approaches to problems involving generic manufacturing technology.

Improve federal coordination with state technology programs. State technology programs fill a niche that the federal government cannot: small-scale, grass-roots efforts involving local businesses, universities and governments. At the very least, the federal government should make sure that its programs do not duplicate or compete with those established at the state level. In addition, the federal government should establish a clearinghouse for state and local initiatives related to the promotion of technology; the clearinghouse would collect and disseminate information on state programs, develop methods to evaluate these programs and provide technical assistance and advice. The provision in the omnibus trade bill that would create such a clearinghouse should be fully implemented.

Encourage Department of Defense efforts to strengthen the U.S. industrial base. The Department of Defense has a vital interest in the health of the U.S. industrial base. In times of national security crisis, the department must be able to rely on a strong and diverse national industrial capacity. With pressures on the federal budget, the United States is unlikely to achieve the necessary scale and scope of funding support for science and technology unless the Pentagon is involved. The Defense Department should use its procurement policies and R&D budget to strengthen the U.S. industrial base. It should focus on conducting critical basic research, developing key technologies and improving production processes, rather than on supporting specific industries or industrial products.

CHAPTER I
TECHNOLOGY AND GLOBAL COMPETITION

The effective development and deployment of technology are critical to America's ability to compete in world markets. Technology has made a vital contribution to America's economic growth and high standard of living. It has improved manufacturing efficiency, created entire industries and served as an important source of U.S. export strength. Leading economists believe that technological change is the single most significant factor behind U.S. productivity growth. Some argue that it is directly or indirectly responsible for two-thirds and perhaps as much as 80 percent of the productivity growth since the Depression.[1]

Today, both domestic and international forces are pushing the U.S. economy toward greater reliance on technology. Structural changes in the economy make the nation more reliant on technology-based sectors and on technology-based improvements of traditional industries as the foundation for national competitiveness. Estimates are that the percentage of GNP derived from these sectors has almost doubled over the past 20 years.[2]

The United States is not alone in its increasing focus on science and technology. According to the National Science Foundation, the United States spent $62 billion on R&D (in real 1982 dollars) in 1970, while the combined spending of Japan, West Germany, France and the United Kingdom was $38 billion; by 1985, U.S. spending had risen to almost $97 billion (in real 1982 dollars), while the combined spending of these other countries had increased to approximately $80 billion.

In today's international economy, virtually all aspects of the commercialization process have become globalized. Recent developments in superconductivity illustrate the new global technical community. Breakthroughs at an IBM European facility in late 1986 set off a chain reaction

throughout the world. Intense verification efforts followed quickly in Europe, Japan, China and the United States; major governmental initiatives were launched; and superconductivity newsletters now routinely report on virtually all research results from universities and laboratories around the world.

The reality of a globalized scientific and technical community has profound implications for corporate strategy and the commercialization process. Since competing technology can be generated worldwide, companies must place increased emphasis on monitoring international sources of innovation, protecting their own technical positions and participating in many national technical communities. U.S. companies, too, now must be as much "hunters and gatherers" of technology as they are generators. Information technology and investment capital flow irrespective of national boundaries, and Americans must adapt to this new situation.

American Strengths

The United States unquestionably enjoys significant strengths in science and technology. U.S. citizens have won an increasing share of Nobel Prizes in each post-war decade, capturing about 60 percent of the total in the 1980s; U.S. technical articles are cited overwhelmingly in many fields; and compared to its major trading partners, the United States has by far the most favorable ratio of receipts/payments for technology, a performance maintained over time at a reasonably constant level.

The most unique and dynamic aspect of the American commercial and technical network, however, is the extraordinary mobility of capital, ideas and people. America's rate of business formation, which is high overall, is particularly strong in technology-related areas, where the net business-formation rate is twice that for non-high-technology establishments. A record number of foreign students continue to flock to American colleges and universities, which are unique in their contribution to national research efforts.

Over the years, the federal government has contributed significantly to America's historic scientific and technological preeminence. The basic framework for U.S. government support of science and technology in the post-war era can be traced to the Vannevar Bush report of 1945. Its title, *Science, the Endless Frontier,* capsulizes the argument that science can yield an infinite stream of benefits to society, that support for science in general is an appropriate role for government, and that more applied areas of work should be left to industry.

For many years, particularly during the two decades following World War II, U.S. industry responded to the support provided by federal science policy and led the world in the development of innovative products and processes. During that period, U.S. firms dominated the commercial application of technology in most industries. With a virtual monopoly on technology, the United States enjoyed what the economist Joseph Schumpeter called the "best of monopoly profits — a quiet life."

Over the past four decades, however, this situation has changed. Countries without a large research base have made up for their shortcomings in research by acquiring technology abroad, often from the United States, and concentrating their industrial resources on the rapid commercial application of new ideas. This approach to innovation and commercialization was built around catching-up with the United States — not by doing independent basic research, but by finding new market applications for existing technology. Excellence in manufacturing, attention to quality and a supportive financial environment that provides a low cost of capital are the key elements of this strategy.

Another factor is also crucial: speed. By rapidly translating new technology into new products and processes, firms in other countries have gained access to new markets and reaped considerable commercial rewards. For several years, the United States, with its large lead in technology, failed to appreciate how critical a role time played in the commercialization process. It was not until several American industries had been dominated by foreign competitors and the United States began to lose its substantial lead in technology that the country began to recognize the extent of the foreign commercial challenge. Part of that challenge relates to the innovation process itself.

Innovation and the Commercialization of Technology

America's post-war preeminence in science and technology resulted largely from its ability to master the so-called "research-driven" model of the innovation process. A new model has emerged, however,

and America's current difficulties in the global technology race have occurred, in part, because neither U.S. industry nor the federal government has responded sufficiently to that new reality.

Simplistically defined, the research-driven model views innovation as a linear process — starting with a major scientific breakthrough, progressing through design, development and production, and ending with marketplace distribution. Consequently, this model emphasizes the importance of basic research. The progression from research breakthroughs to market is most likely for radical discoveries that represent major technical advances. Such discoveries may reorder existing economic relations significantly or create entirely new markets. Indeed, the United States has excelled at this mode of innovation, with American companies and engineers having produced most of the major technical breakthroughs since World War II.

As a growing number of observers recognize, however, the research-based model offers, at best, a partial explanation of the innovation process. It is far more complex than suggested by this linear concept. Consequently, the research-based model must be supplemented by another view that focuses more on market-driven applications of technology. This approach involves systematic, incremental improvements in products and processes that arise in response to market needs. These improvements — which, in the aggregate, can be as significant as a radical discovery, if not more so — depend on day-to-day adaptation as firms react to ever-changing market signals. Success depends on a team effort that includes carefully focused research, design for manufacturing, attention to quality and continuous market feedback.

This new model suggests that innovation is better described as an interactive or reiterative, interdependent process in which design, manufacturing and product development all drive research and, at the same time, are highly dependent on research. In policy terms, it suggests that science and engineering must be viewed as closely linked and as both the product and the source of technology. It also suggests that products must be rapidly advanced to the marketplace so that market feedback can be factored into new research and improved technologies. One of the key distinctions between the linear model of innovation and this new model is that the former emphasizes generic research while the latter emphasizes more market-specific research.[5]

Commercialization involves applying fresh ideas to market opportunities to create new and better products. It is the primary job of the private sector. Innovations are brought to market through a firm's internal operations, which combine research, concept identification, development and implementation. The research stage begins the linkage between market needs and specific technical ideas for new products or processes. As work proceeds, the available pool of ideas is narrowed and specific concepts are selected for development. Once in development, they are judged according to technical feasibility, quality, cost and customer acceptance. Decisions made in this development stage are the ones that control the rate of technological progress in many major U.S. industries. Ultimately, the innovation is implemented in the form of a new or improved product or process that yields a return to the firm. Distinct lines cannot be drawn between phases, nor do they necessarily proceed in a sequence. On the contrary, most firms are involved in a continued process of feedback as they perceive and respond to a changing market.

Many underlying external factors also influence the commercialization process. Labor skills, customer wants, government regulations, the cost of capital and the ability to protect the R&D investment all bear on the ability of firms to commercialize technology successfully. Their impact on each industry is different. A critical aspect of managing the process is balancing these factors in an effort to focus scientific and technical capabilities on a market-driven goal.

American Weaknesses

Much of the U.S. failure to exploit technology for commercial advantage lies in not adequately appreciating the importance of manufacturing and not properly balancing short-term and long-term goals. The neglect of manufacturing arose largely out of the complacency of the 1950s and 1960s when the United States dominated international markets. Top U.S. managers began to focus on marketing and finance at the expense of manufacturing and, as a result, failed to manage the investments in worker skills, plant and equipment necessary for a strong manufacturing capability.

Today, foreign companies are often beating U.S. companies, not with low wages, but with more efficient manufacturing processes. For example, Japanese manufacturers, who have a reputation for efficiency, spend two-thirds of their R&D budgets on process innovations, while U.S. manufacturers spend only one-third.[4]

The importance that Japan places on manufacturing as a source of its economic future should not be underestimated. In the past, the Ministry of International Trade and Industry has explicitly set economic policies and priorities for Japanese industry. In its 1987 White Paper on International Trade, MITI described how Japan's R&D manufacturing muscle could be used to advance Japan's economic agenda around the world.

> " . . . Japanese industry has built up a store of know-how and advanced productive technology in the processing and assembly fields. The supply of this know-how, in conjunction with capital, to both the developed and developing countries, would do a great deal to help activate the economies of those countries. . . . Japanese industry must press ahead with internationalization in every field."[5]

Closely linked with problems in U.S. manufacturing is the American preoccupation with short-term goals. All too often American management is under pressure to improve the bottom line in the next quarter, without regard to how their actions will affect business in the future. This problem is not simply a result of myopic management; it is systemic. The cost of capital, budget and trade deficits, the tax system and the pressure of financial markets all contribute to the problem.

Unfortunately, preoccupation with short-term goals can be devastating for technology-based industry. R&D, manufacturing excellence and the creation of a talented labor force are inherently long-term propositions. Science and technology thrive in organizations where there is a critical mass of highly skilled talent and a sense of mission. Systematic investments in research, plant and equipment, and in training and retraining are essential.[6]

Problems in manufacturing and in setting long-term goals attest to the fact that American managers often lack the benchmarks to understand and evaluate their companies' performance in the R&D cycle. As a result, they have difficulty accurately identifying specific problem areas. Better information about each of the steps in the R&D cycle is required, from research through design, manufacturing and marketing. More important, management needs to establish a new set of benchmarks that will allow it to survey the private sector's R&D cycle and address problems.

Succeeding in the global scientific and technological race depends on an ability to integrate a number of capabilities over a sustained period of time. Focused research, excellence in manufacturing, commitment to quality, incentives for worker motivation and upgraded employee skills are all part of the process.

There is no doubt that the commercial challenge to American innovation is the result of problems within American industry. But industry's performance is vitally affected by federal macroeconomic policy, regulatory policies and by government science and technology policies.

The following chapters and subsequent recommendations focus on the role of the federal government. Just as industry must integrate capabilities more effectively, so must government; Chapters 3 and 4 demonstrate the extent to which U.S. public policy-making remains fragmented and uncoordinated.

Beyond the structural problem lies an even more significant issue; in many ways, the federal government has failed to adapt its policies to the new, market-driven model of innovation. Hence, America's hands are tied by policies geared to another era that do not address today's competitive realities.

In staking out a forceful federal role in the advancement of scientific knowledge, the government has tended to ignore technology. The American people and public officials too readily assumed that preeminence in science automatically confers technological and commercial success as well. It does not — at least since the rapid gains by foreign nations in the past two decades. America assumed that government support for science would be adequate to provide for technology. It is not. In all too many sectors, America took technology for granted. Today, the nation is paying the price for that complacency. The extent of the problem is described in the following chapter.

Endnotes

[1]The first effective effort to measure the impact of technology on the U.S. economy is credited to Robert Solow. See "Technical Change and the Aggregate Production Function," *The Review of Economics and Statistics*, 1957. Many economists have since expanded on these concepts.

[2]Chris Freeman, *The Economics of Industrial Innovation*, Cambridge: MIT Press, 1982.

[3]See Lewis M. Branscomb, *Policy for Science and Engineering in 1989: A Public Agenda for Economic Renewal*, April 1988.

[4]See Edwin Mansfield, "Industrial R&D in Japan and the United States: A Comparative Study," American Economic Review, May 1988.

[5]Ministry of International Trade and Industry, *White Paper on International Trade*, Tokyo, 1987, p. 173.

[6]Ian Ross, "Information Technology and U.S. Technological Competitiveness in the 1990s," in *Vision for the 1990s: U.S. Strategy and the Global Economy*, edited by Daniel Burton, Jr., Victor Gotbaum and Felix Rohatyn, Cambridge: Ballinger Press, 1988.

CHAPTER II

THE COMMERCIALIZATION PROBLEM

There is no question that the United States enjoys significant strengths in science and technology, described in the previous chapter. America's primary problem in the science and technology field relates neither to entrepreneurship, research nor the performance of its universities, but to the commercial application of technology. Considerable evidence suggests that America is failing to commercialize the kinds and quality of technology that the market demands.

The problem is relatively new. For many years, particularly the two decades following World War II, U.S. firms dominated the commercial application of technology in most industries. Over time, however, foreign companies assimilated state-of-the-art technology, often American in origin; improved it; generated their own products and processes; and brought them skillfully to market.

No single measure can prove or account for deficiencies in the U.S. ability to commercialize technology rapidly. In the aggregate, however, a variety of "warning signals" point to a problem. These indicators include the erosion of the U.S. high-technology trade surplus, problems in specific industries, patent trends and the educational performance of U.S. students.

The U.S. High-Technology Trade Balance

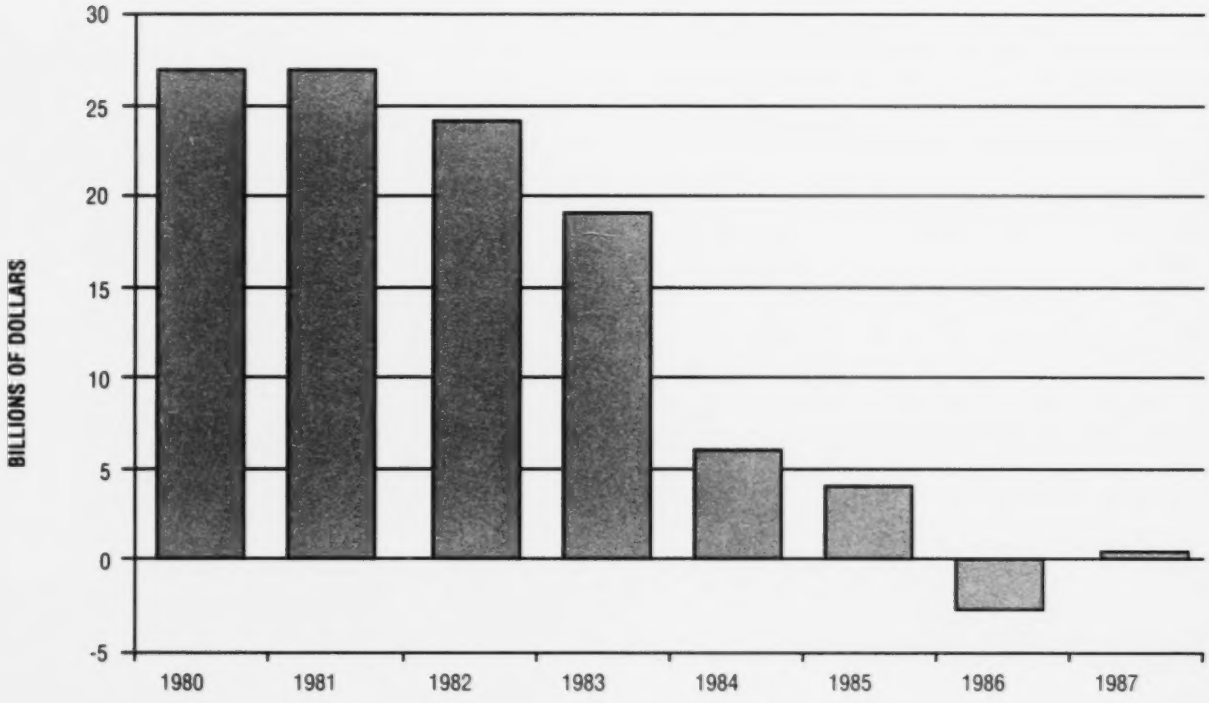
Some of the evidence of the commercial challenge to American innovation relates directly to technology-based products. In the post-war era, technology has been a leading U.S. export strength. The U.S. high-technology trade surplus, however, declined precipitously during the early 1980s when the dollar was high. It turned negative for the first time in 1986. In 1987, despite the significant drop

in the dollar, the United States posted only a modest surplus in high-technology trade (see *Figure 1*).

The performance of individual industries reflects this overall trend. Since 1970, many U.S. industries have lost their dominant position in the domestic market to foreign competitors. *Figure 2* lists some technologies that were pioneered by the United States. In many instances, U.S. firms once controlled much of the domestic American market. Today, however, even though the markets are large, U.S. firms have been displaced to an important extent by foreign competitors (see *Figure 2*).

FIGURE 1

THE U.S. TRADE POSITION IN HIGH TECHNOLOGY 1980-1987



Source: The National Science Foundation

FIGURE 2

THE EROSION OF THE U.S. SHARE OF TECHNOLOGY MARKETS

TECHNOLOGY	PIONEERED BY	U.S. COMPANIES' SHARE OF DOMESTIC AMERICAN MARKET (percent)				ESTIMATED 1987 VALUE OF U.S. MARKET (millions)
		1970	1975	1980	1987	
Phonographs	U.S.	90	40	30	1	$ 630
Televisions						
Black & White	U.S.	65	30	15	2	$ 175
Color	U.S.	90	80	60	10	$ 5,150
Audio Tape Recorders	U.S.	40	10	10	1	$ 500
Video Cassette Recorders	U.S.	10	10	1	1	$ 2,895
Ballbearings	Germany	88	83	71	71	$ 1,657
Machine Tools						
Horizontal Numerically Controlled Lathes	U.S.	100[1]	92[1]	70	40	$ 401
Machining Centers	U.S.	100[1]	97[1]	79	35	$ 485
Telephone Sets	U.S.	99	95	88	25	$ 2,000
Semiconductors[2]	U.S.	89	71	65	64	$ 19,100[1]
Semiconductor Manufacturing Equipment[3]	U.S.	100	90	75	75	$ 1,856
Cellular Telephones	Scandinavia/U.S.	--[4]	--[4]	--[4]	40	$ 740
Facsimile Machines	U.S./Japan	--[4]	--[4]	--[4]	--	$ 750

[1] Estimates
[2] Data is for semiconductor merchant companies only. U.S. company share includes production of foreign subsidiaries operating in the United States.
[3] Estimates only. No official data exists.
[4] Not introduced into the U.S. market.

Source: International Trade Administration, U.S. Department of Commerce

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Industry-Specific Problems

The deterioration of the U.S. high-technology trade surplus and the trade performance of specific U.S. industries attest to the fact that foreign companies have made dramatic inroads into a number of sectors pioneered and previously dominated by Americans. Examples can be found in a number of industries, including consumer electronics, semiconductors, superconductors and pharmaceuticals.

Consumer electronics

Over the past century, U.S. industry traditionally enjoyed a strong position in consumer electronics, but during the last 15 years, the United States has lost this market to foreign manufacturers. The American era of consumer electronics manufacturing began with Edison's invention of the phonograph in 1887. This was followed by a string of other U.S. inventions, including the cathode ray tube (1897), wireless transmission of speech (1900), radio broadcasting (1920), television receivers (1923), magnetic wire recorders (1946), transistors (1947), color televisions (1954), portable radios (1954) and home video cassette recorders (1963). Until 1970, the United States dominated these fields.

Since then, it has lost virtually the entire market. In 1970, U.S. industry enjoyed almost a 100 percent share of the American consumer electronics manufacturing market; today, it has less than 5 percent, despite the fact that the consumer electronics market has more than trebled to $25 billion in annual sales over the last decade.

One of the most troubling aspects of the erosion of the U.S. manufacturing presence in consumer electronics is the repercussions for other parts of the electronics industry. This connection has been likened to the biological food chain: when one link is weakened, other links feel the injury. While the United States continues to enjoy a considerable market presence in related fields — such as home computers, telephones, calculators and video games — the erosion of the U.S. position in consumer electronics could affect the U.S. lead in these other areas.

High-definition television is an example of this linkage. Although the United States, along with Japan and some European countries, still possesses the technology for high-definition television, U.S. industry no longer has the capacity to manufacture, market and distribute it. The real challenge of foreign dominance of high-definition television technology, however, is not simply the television market (which is projected to reach $40 billion in worldwide sales in 2007), but the ripple effect on other segments of the electronics industry, such as semiconductor manufacturing, test equipment, software, manufacturing equipment in general and, ultimately, telecommunications and computers.[1]

Semiconductors

Semiconductors, which are central to the entire computer industry, have been the focus of extensive attention in public policy circles in recent years. In 1959 two Americans, Robert Noyce and Jack Kilby, almost simultaneously invented the integrated circuit. During the 1960s and 1970s, U.S. companies dominated the world market for the design and manufacture of semiconductors and computers. In the early 1970s, however, Japan targeted semiconductors as a strategic industry. By 1980, Japanese companies had surpassed U.S. merchant semiconductor firms in the design and manufacture of the latest generation of semiconductor devices. By 1983, Japan-based firms' share of the world market was equal to that of U.S.-based firms. By 1986, the Japanese had taken 65 percent of the world market, while the U.S. share had fallen to under 30 percent.[2] These market shifts are even more dramatic for dynamic random access memory products (DRAMS), which constitute a core technology (see *Figures 3A and 3B*).

Superconductors

Similar concerns are being raised about high-temperature superconductors. In 1987, two researchers in an IBM lab in Zurich pioneered the breakthrough in superconductors. This scientific advance was confirmed quickly by scientists in Tokyo and subsequently extended by U.S. researchers working at the University of Houston. Soon thereafter, Japan's Ministry of International Trade and Industry established an R&D consortium for superconductors. Japanese companies have also begun to file a flood of patent applications. The speed of Japan's response has raised public concern about America's ability to rapidly commercialize this discovery and has driven home the commercial challenge to American innovation.

FIGURE 3A

MEMORY PRODUCTS: WORLD MARKET SHARE
percentage of world shipments

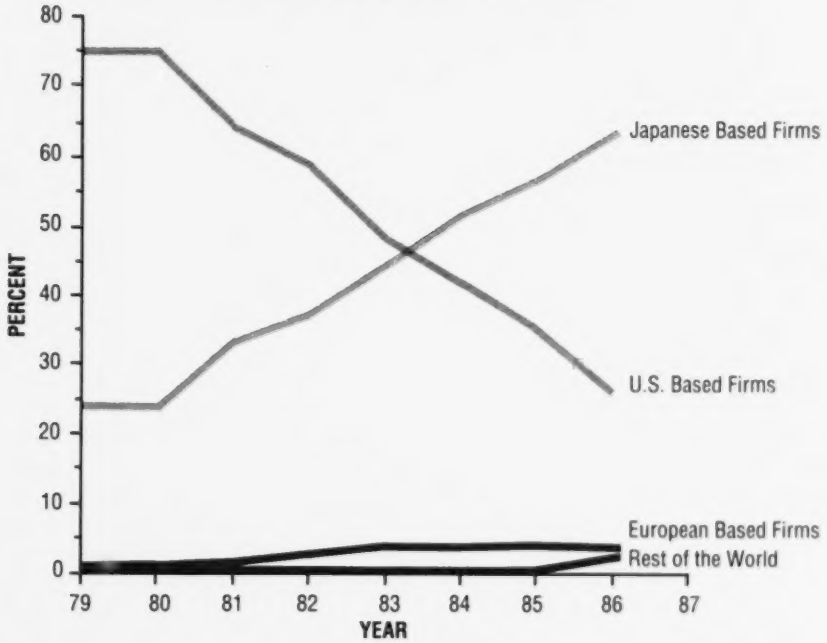


FIGURE 3B

WORLD SHARE OF DYNAMIC RANDOM ACCESS MEMORY PRODUCTS (DRAMS)

	1975	1980	1987*
U.S.	95.8%	55.6%	17.9%
Japan	4.2%	39.4%	73.0%
Europe	—	5.0%	2.0%
Rest of World	—	—	7.1%

* In 1987, the value of the world market for DRAMS was $2.6 billion.

Source: Dataquest

Pharmaceuticals

The commercial challenge to American innovation also extends to the pharmaceutical industry. Over the past decade, American pharmaceutical companies have experienced a "drug lag" due to the lengthy approval procedures of the U.S. Food and Drug Administration. As a result, significant U.S. and foreign discoveries often are approved abroad well before they are approved in the United States. This deprives U.S. companies of significant sales and profits and undermines incentive to invest in R&D to develop new drugs. From 1970 to 1979, of the 24 most significant new drugs introduced in the U.S. market with 1979 sales over $20 million, 13 were discovered in American laboratories, 10 were discovered overseas and one was discovered jointly. Despite the fact that U.S. laboratories were responsible for more than half of these new drugs, 20 of the 24 were approved in the United Kingdom an average of about two-and-one-half years before they were approved in the United States. Of the 13 U.S. discoveries, 11 were approved in the United Kingdom an average of two years before they were introduced in the United States.[3]

This "drug lag" not only has consequences for American patients who could be helped by these drugs, but also for American companies which lose significant sales as a result of these delays. The delay in approval and marketing of the 11 drugs mentioned above represented lost U.S. sales of $1 billion to U.S. pharmaceutical companies during the patent life of the drugs. Despite repeated industry complaints about the slow pace of the federal approval process, there is little evidence that this problem has been remedied.

Foreign-based firms are also increasing their share of innovative R&D leading to new products. From 1976 through 1980, the U.S. research-based pharmaceutical industry contributed 70 new drugs to world markets, more than one-fourth of the total and twice the number originating from Japan. In sharp contrast, during the last five years, Japan introduced 60 new drugs into world markets as compared with 58 originating from the United States.[4]

Patents

Patent statistics also point to troubling trends. Between 1969 and 1982, the rate at which U.S. residents patented their discoveries abroad decreased by about 50 percent. Only the United Kingdom experienced a decline of similar magnitude to the United States.

In the meantime, foreign applicants increased their share of U.S. patents from about 35 percent of grants in 1975 to 46.6 percent in 1987. Most of this growth is accounted for by a more than doubling of the Japanese share. Looking beneath the aggregate numbers, these data show that the most important patents are held by the Japanese in an increasing number of fields. Starting more than a decade ago, patents awarded to Japanese inventors were cited more frequently by those applying for new patents than those awarded to Americans. And the gap appears to be growing (see *Figures 4 and 5*).

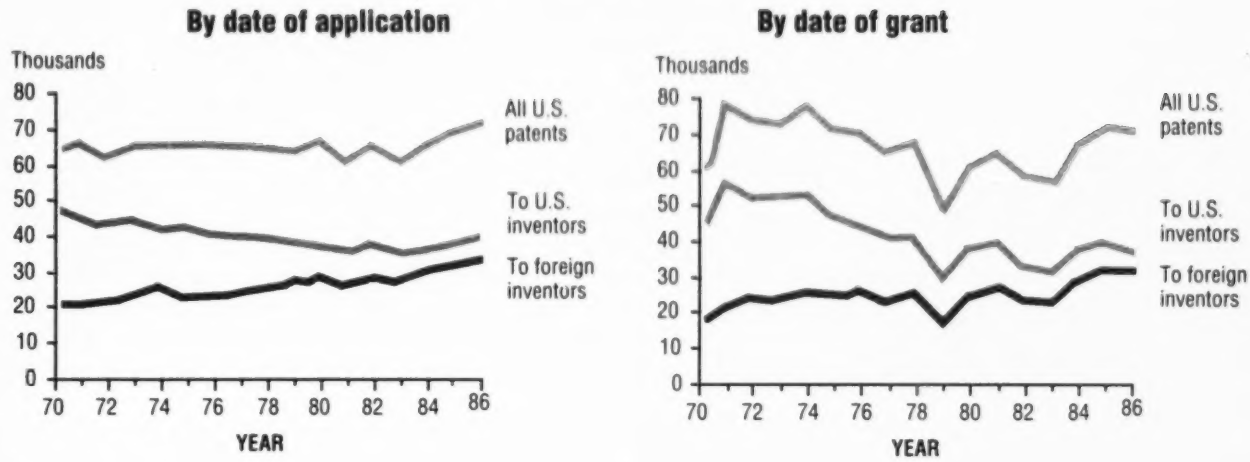
Fiber optics provide an interesting case study of the importance of patents. In the late 1960s, the optical fiber was invented in the United States by Corning Glass Works. Corning patented this invention in the United States in the mid-1970s, but many of the patents were not issued in Japan for more than 10 years, which left Corning's technology unprotected in this critical market. For much of the 1970s, Corning was effectively closed out of the Japanese market, first by Nippon Telegraph and Telecommunications' procurement policies and then by NTT's "design" specifications for suppliers. In the meantime, Japan's Ministry of International Trade and Industry designated fiber optics a strategic industry, provided government-backed research and development and attracted the necessary investment from Japanese companies. The inevitable result was surplus capacity in Japan and a push for exports.

By 1983, Sumitomo Electric and other Japanese manufacturers were selling fiber optics at well below cost in the United States. Although Corning successfully brought suit against Sumitomo for patent infringement in the United States, the U.S. International Trade Commission ruled that the infringement was not causing significant loss of sales or profits to Corning and declined to penalize Sumitomo. Corning then took the case to the U.S. district courts, which in 1987 ruled that there had been willful infringement. By the time of this ruling, however, Corning's patents had only a short period of validity left.

The result was that Corning Glass Works, after investing $200 million to develop a patented

FIGURE 4

U.S. PATENTS GRANTED
by nationality of inventor



Source: U.S. Patent Office

FIGURE 5

CITATIONS FROM U.S. PATENTS TO EARLIER U.S. PATENTS
by country of inventor of cited patents

Year of cited patents	Country of inventor									
	United States	Japan	Netherlands	United Kingdom	West Germany	Canada	Sweden	France	Switzerland	Italy
	Citations per citable patent									
1975	3.05	3.30	2.93	2.87	2.65	2.57	2.46	2.43	2.42	2.41
1983[1]	0.68	0.92	0.62	0.59	0.59	0.53	0.51	0.58	0.57	0.49

[1] These numbers are expected to increase as more citations are made to 1983 patents in later years.

Source: National Science Foundation

process for manufacturing optical fibers, was blocked from capitalizing on its early technological advantage in Japanese markets and was unable to prevent Sumitomo from using Corning's patented process to sell fiber optics in the United States.

Another interesting example is provided by the experience of Fusion Systems Corporation, a small high-technology company in Maryland that makes patented ultra-violet lamps. In 1976, Fusion began selling its products in Japan. In 1977, it noticed that Mitsubishi Electric was filing numerous patent applications in Japan on similar technology, a process known as "patent flooding," a common practice in Japan that entails patenting multiple minor variations of the original patented design. By 1985, Mitsubishi had filed almost 200 patent applications. These patents surrounded Fusion's core patent. When Fusion tried to modify its product to

meet the individual needs of its customers, it found that in many cases Mitsubishi already held patents on the modified designs. As a result, Fusion's right to sell in Japan was threatened.

In an attempt to avoid a long and costly legal battle, Fusion offered not to oppose Mitsubishi's applications in Japan if Mitsubishi would agree not to assert any of its patents against Fusion. Such an agreement would have allowed Fusion to continue selling in Japan. Mitsubishi countered by suggesting that both sides cross-license their technology. Although this is a common practice with large U.S. companies, which view it as a price of doing business in Japan, Fusion — a small company whose only real advantage is its technology — could not. Fusion feared that cross-licensing would eventually undercut its sales in Japan, and eventually lead to its competing against its own technology in world markets. As of August 1988, the two companies were still negotiating.

The growing concern that Japanese firms may be using their patent system to corner emerging technologies and freeze out competitors extends to the field of superconductors, which some experts project to be a $20 to $30 billion market by the end of the century. By early 1988, Japanese corporations had filed more than 2,000 patent applications for superconducting materials and devices, which amounts to a $40 million investment in patent filing fees alone.

Science and Engineering Education

America's ability to commercialize technology is linked closely to its supply of skilled technical workers. Clear signs, however, show that the nation faces significant human resource problems. The challenge is two-fold. First, the nation's most experienced scientists and engineers, who were recruited shortly after the launching of Sputnik, will be retiring in the 1990s. Second, by the year 2000 the number of jobs requiring college degrees will increase dramatically. Unfortunately, the education system is failing to produce the American scientists and engineers needed to meet future demand. With a decreasing number of 18-year-olds in the United States and a declining percentage of high school graduates choosing science and engineering, a shortfall of more than 500,000 scientists and engineers is projected by the year 2010.[5]

Leadership in science and technology cannot be maintained unless the education pipeline — from elementary school through graduate school — is repaired so it yields a larger and more diverse group of world-class scientists and engineers. The United States needs to do a better job of preparing American elementary and high school students for college-level work in science and engineering; of stimulating them to pursue engineering; and of providing them with incentives for graduate study. As the chart on the next page demonstrates, the number of U.S. students interested in science and engineering drops sharply from high school through college (see *Figure 6*).

Major problems in science and engineering education include the poor performance of U.S. primary and secondary school students in science and mathematics in comparison to students in other industrialized countries; several decades of underinvestment in facilities and equipment; the increasing inability of engineering schools to attract adequate numbers of qualified U.S. students into graduate programs; and the inability of engineering schools to fill their faculty vacancies.

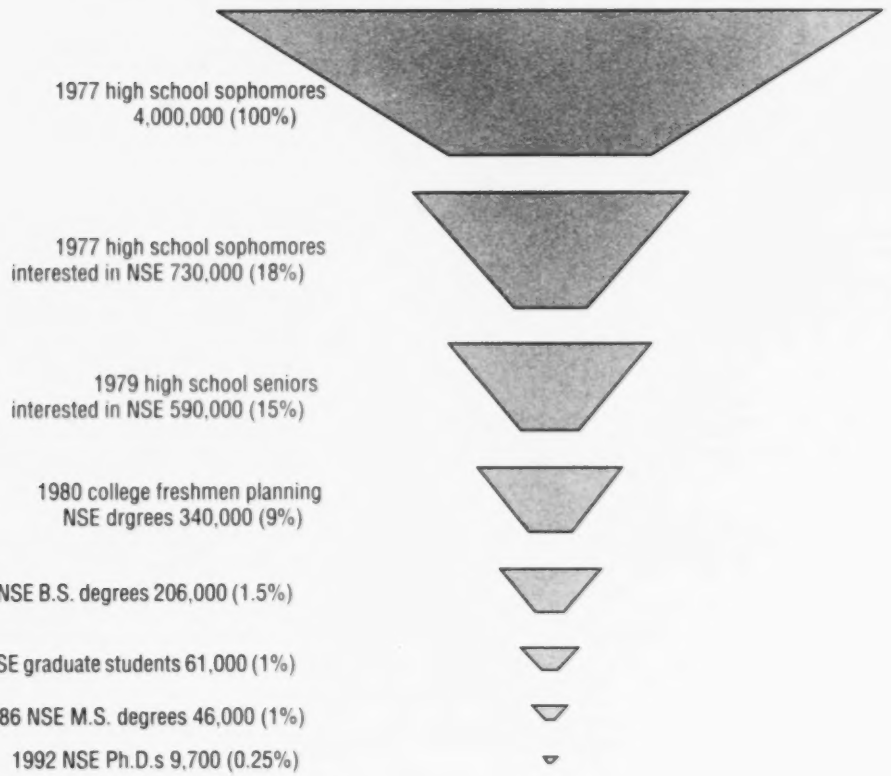
The problem begins in elementary school. Elementary schools, especially in large urban school systems, suffer from chronic shortages of good mathematics and science teachers, offer little hands-on laboratory science and have low expectations of teacher performance. One of the early points at which students in the United States drop out of the mathematics-science pipeline is in grades 5 through 8. Decisions about science and math courses made at this time can substantially foreclose later choices.

The pattern continues in high school. American students take fewer science and math courses in high school than students in many other industrialized nations. Consequently, they score lower on international tests in these areas, and fewer are prepared to pursue higher education in these fields (see *Figure 7*).

Problems persist in higher education. In 1985, almost 8 percent of all bachelor's graduates earned their degrees in engineering, up from 4 percent a decade earlier. Much of this increase reflected student interest in the relatively new field of computer science. This decade-long trend, however, disguises the fact that all of the numbers have now started to turn downward. The college-age population peaked in 1983; freshman enrollment in

FIGURE 6

NATURAL SCIENCE/ENGINEERING PIPELINE:
Following a Class from High School through Graduate School


1977 high school sophomores
4,000,000 (100%)
1977 high school sophomores
interested in NSE 730,000 (18%)
1979 high school seniors
interested in NSE 590,000 (15%)
1980 college freshmen planning
NSE drgrees 340,000 (9%)
1984 NSE B.S. degrees 206,000 (1.5%)
1984 NSE graduate students 61,000 (1%)
1986 NSE M.S. degrees 46,000 (1%)
1992 NSE Ph.D.s 9,700 (0.25%)

Source: U.S. Congress Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School*, Washington, D.C., 1988

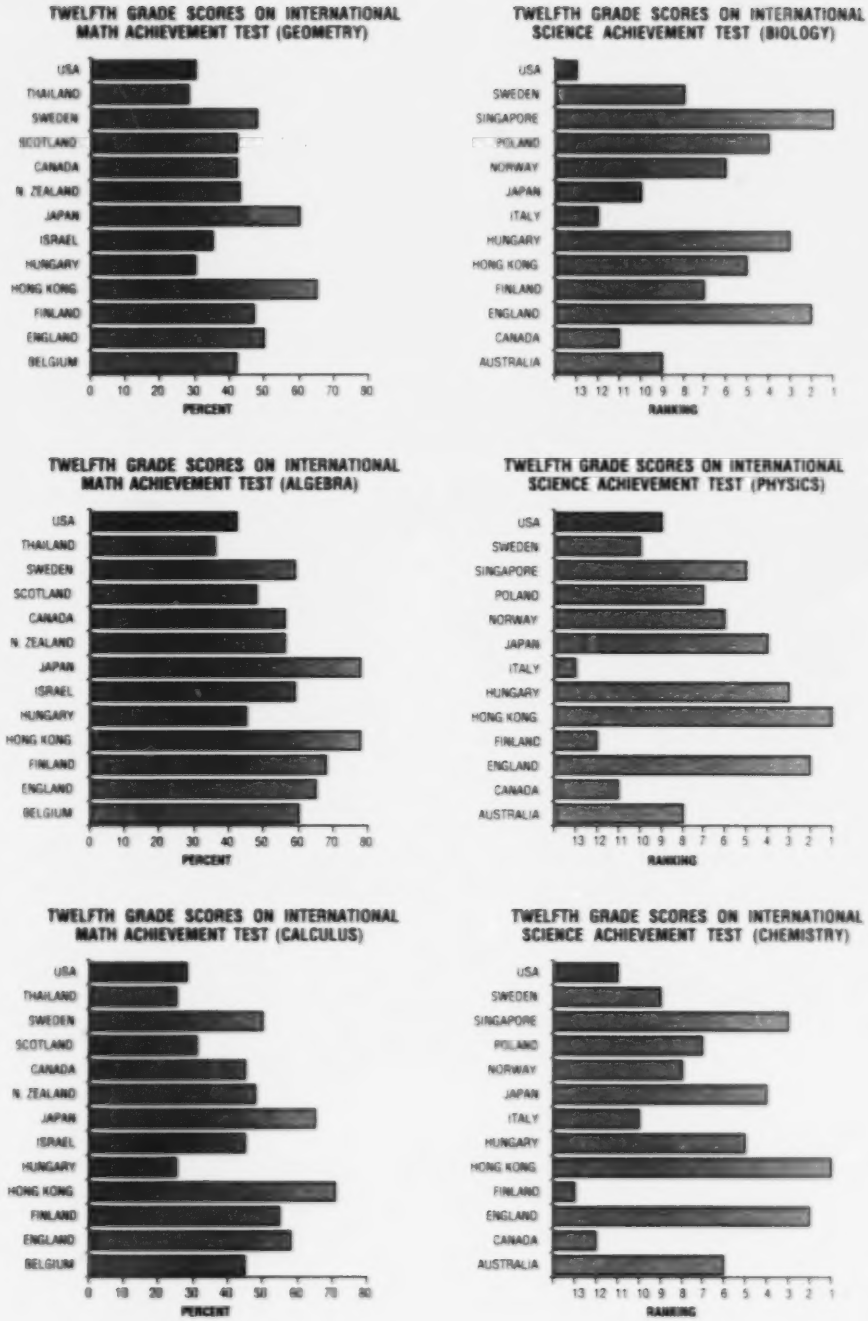
engineering started down in 1982 and had dropped 14 percent by 1986; and bachelor's degrees in engineering topped out in 1985 and 1986.[6]

The number of college-age students will continue to decrease through 1996, for a total drop of about 25 percent, and then hold at about that level until 2005. But the number of freshman students choosing engineering is declining even faster than these demographic trends would suggest. This decline is due to the drop in job offers to engineering graduates in the past three years and to the fact that women and minorities — who have traditionally been under-represented in science and engineering — constitute a growing share of the college-age population.

If the United States is to train adequate numbers of scientists and engineers in the future, it will have to reach out to these traditionally under-represented groups. In the year 2000, these groups will account for about 85 percent of the new entrants into the nation's work force. Their involvement in science and engineering is essential to the nation's future strength in technology.

Fortunately, the decrease in the proportion of American freshmen choosing science and engineering majors has been compensated for by many foreign students enrolling in U.S. universities in these fields and colleges' success in attracting more

FIGURE 7



Source: International Association for Evaluation of Educational Achievement. Reprinted from *Changing America: The New Face of Science and Engineering*, Task Force on Women, Minorities and the Handicapped in Science and Technology, 1988

older and part-time students. But a significant portion of foreign-born technical professionals trained in the United States is not employed here, and older and part-time students tend not to graduate in science and engineering.

Foreign students represent approximately 40 percent of enrollments in U.S. graduate schools of engineering and they receive more than half of U.S. doctorates in engineering (see *Figure 8*). Without foreign-born students, there would be a severe shortage of qualified engineering personnel in both industry and universities. Clearly, the United States needs to encourage foreign engineering students to remain here after they have completed their education. Present immigration laws limit the opportunities for U.S. firms to employ these foreign nationals, however, and consideration should be given to modifying these laws.

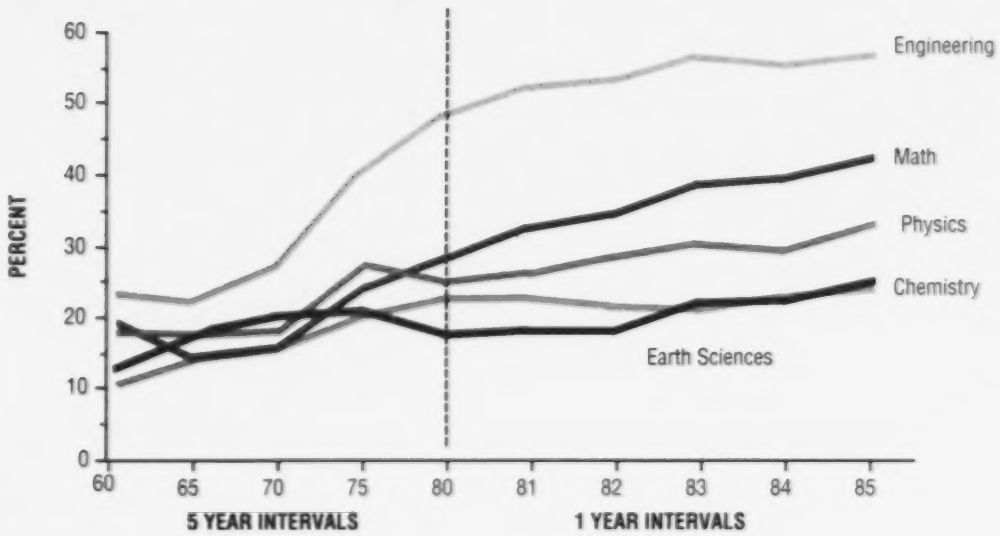
Teacher shortages

The shortage of competent math and science teachers and engineering faculty is one of the most important barriers to raising the quality, scope and number of engineering programs. According to the National Science Foundation, 60,000 math and science teachers in America's secondary schools are not fully qualified, and by 1995 the United States will need an estimated 300,000 additional secondary-school math and science teachers.

According to a 1985 survey by the American Society for Engineering Education, approximately 1,300 authorized positions for engineering faculty are vacant, which represents 8.8 percent of the total number of faculty positions.[7] Significantly, more than half of the positions vacant in 1985 also were vacant in 1984. The greatest shortages were among computer and electrical engineers. Many

FIGURE 8

DOCTORAL DEGREES AWARDED TO FOREIGN STUDENTS AS A PERCENT OF ALL DOCTORAL DEGREES FROM U.S. UNIVERSITIES by field



Source: Division of Science Resources Studies, National Science Foundation

engineering school administrators believe that the number of authorized full-time positions is not adequate to "maintain and restore quality in their programs." Engineering deans reported that authorized full-time faculty positions are only about 89 percent of the number required. This translates into 22,000 full-time engineering faculty positions and an actual shortage of over 18 percent.[8] To compensate for the shortage of engineering faculty, U.S. engineering schools have relied on foreign faculty. At present, over half of all U.S. assistant professors in engineering under the age of 35 are foreign-born. When the many science and engineering faculty trained in the 1950s retire in the 1990s, as expected, the faculty shortage will be exacerbated.

Endnotes

[1]Pat Hill Hubbard, *New Directions in Home Video Technology*, Testimony presented to the Subcommittee on Science, Research and Technology. House Committee on Science, Space and Technology, Washington, D.C., June 23, 1988.

[2]For a complete discussion, see Clyde V. Prestowitz, Jr., *Trading Places: How We Allowed Japan to Take the Lead*, New York: Basic Books, 1988, pp. 26-70.

[3]Unpublished study of commercially and therapeutically important drugs of the 1970s, Thomas Althuis.

[4]Pharmaceutical Manufacturers' Association.

[5]*Changing America: The New Face of Science and Engineering*, Interim Report of the Task Force on Women, Minorities, and the Handicapped in Science and Technology, Washington, D.C.: 1988, p. 9.

[6]Betty M. Vetter, "Demographics of the Engineering Student Pipeline," *Engineering Education*, May 1988, p. 735.

[7]One hundred eighty out of 270 schools, representing 73 percent of total graduate and undergraduate enrollments, responded to this survey. Extrapolating from this data would lead to the conclusion that there are about 20,400 full-time authorized faculty positions and about 1,800 vacancies.

[8]See Paul Doigan and Mack Gilkeson, "ASEE Survey of Engineering Faculty and Graduate Students, Fall 1985," *Engineering Education*, October 1986, pp. 51-56.

CHAPTER III
THE FRAGMENTED PUBLIC POLICY ENVIRONMENT

Remedying the problems described in the previous chapter will require a series of government actions. There are disturbing signs, however, that in many areas federal policies are undermining the effective commercialization of technology.

While the private sector is primarily responsible for commercializing new technology, the federal government creates the environment in which the commercialization process takes place. In some areas — such as macroeconomic policy, the organization of federal programs and infrastructure — the government's impact is indirect. In other areas — such as the federal R&D budget, government R&D incentives, the federal laboratory system and the regulatory and legal environment — government's impact is much more direct. In general, however, the federal government has not addressed technology as an issue. Therefore, the policies and processes in place tend to inhibit rather than promote the rapid commercialization of technology.

Macroeconomic Policy

On the most basic level, private sector decisions about the commercialization of technology are affected by federal monetary and fiscal policies. Government borrowing, the money supply and tax laws strongly influence the domestic cost of capital. Since the commercial application of technology involves significant short-term investments in R&D that are only rewarded over the long-term, the commercial applications are highly sensitive to the cost of capital. The fact that the cost of capital in the United States is higher than in many other countries, notably Japan, puts American firms at a disadvantage in the race to commercialize technology.

Low U.S. savings rates add to the investment problems created by the relatively higher U.S. cost of capital. Adequate levels of domestic saving are essential to support the domestic investment necessary for increased growth and productivity. Total national savings include personal savings, business savings, state and local government surpluses and federal savings. Since 1981, high levels of federal dissavings in the form of large budget deficits have had a profound effect on total levels of domestic savings available for investment.

From 1981 to 1987, federal dissavings averaged 4.2 percent of the Gross Domestic Product (GDP). During the same period, personal and business savings decreased from 18 percent of the GDP in 1981 to approximately 15 percent in 1987, while state and local government surpluses declined from 1.5 to 1.0 percent, reducing further the absolute levels of national savings. Large budget deficits in a low-savings society present America with a dilemma: either it can forego investment or borrow capital from abroad to finance domestic investment that would not take place otherwise.

The United States has chosen to finance domestic investment (and consumption) through foreign borrowings, which in 1987 exceeded $155 billion — 22 percent of the total investment that year. Borrowing from abroad has significant economic costs. America mortgages its economic future by transferring domestic resources abroad to pay interest and principal on foreign-held assets. Had the foreign resources been used to sustain higher levels of investment, America would have increased its productive resources to meet these financing requirements. Unfortunately, however, foreign borrowing went largely to subsidize domestic consumption; even with the inflow of foreign funds, domestic investment as a percentage of the GDP declined between 1981 and 1984.[1]

International currency swings also affect the commercialization process. By effectively raising the prices of U.S. goods and services in world markets and giving foreign competitors a price advantage in the U.S. market, the high dollar of the early 1980s stripped many American technology companies of the sales and profits necessary to make systematic, long-term investments in R&D. In addition, trade policies, such as U.S. export controls and the inadequate protection of intellectual property, have undermined the worldwide sales of U.S. companies. The result can be seen in the deterioration of the U.S. high-technology trade surplus.

Government Organization

Government procedures and organization have a critical impact on the development of technology. Even the best-conceived technology initiatives can be frustrated by the lack of coordination among responsible agencies, the inability to implement policies or unproductive relationships among the principal participants. In large part, such problems are the legacy of historical circumstances. Because public policy has not addressed the issue of the commercial application of technology, government policies often tend to impede rather than contribute to the rapid commercialization of technology.

No line agency of the federal government has broad responsibility for research and other activities related to civilian technology or for strategic coordination of technology policy at the national level. In the Executive Branch, responsibility for R&D is dispersed among 12 agencies. In Congress, the civilian science budget alone is divided among 9 of 13 different appropriations subcommittees, and there is no mechanism for devising reasonable compromises or setting priorities. For example, although the Administration's FY 1988 proposal to double the National Science Foundation's budget was greeted with enthusiasm by Congress, the first-year funding target was not met because the subcommittee responsible for determining budget had to choose between funding for science and funding for housing subsidies in the Housing and Urban Development budget.

Furthermore, there is little federal focus on technology's impact on the economy. Individual agencies are responsible for the research and technology that relates solely to their particular missions. Only the Department of Energy and the Department of Agriculture extend their focus to economic performance and then only in specific sectors.

The one organization that provides an overview of federal research and other activities related to economic performance is the White House Office of Science and Technology Policy. The office advises the President and helps coordinate federal R&D

activities, but it has no line functions and a small budget, with staff mostly on temporary loan from other agencies.

The Department of Commerce has broader economic responsibilities. Its National Bureau of Standards is the only federal lab explicitly charged with serving the needs of U.S. industry; its small Office of Productivity, Technology and Innovation works to create a favorable climate for industrial innovation, technology and productivity; and its National Technical Information Service serves as a resource for scientific and technical information.

The National Science Foundation also has a series of broader responsibilities. It supports education, research and information transfer in most scientific and engineering fields and, in effect, serves as the general science and engineering agency of the federal government. Its budget, however, accounts for only 2.5 percent of total government R&D funding.

The dispersed responsibility for technology apparent in the federal government is unusual among industrialized countries. Most national governments maintain a ministry of science and technology or a ministry of trade and industry that has broad responsibility for research and technology-related activities.

Four issues arise from the U.S. situation: 1) the lack of an organizational focus on technology; 2) inadequate coordination and implementation of existing programs; 3) inadequate policy continuity over time; and 4) inadequate modes of private-public communication and cooperation. These concerns are discussed below.

First, because the primary goals of technology-related agencies (such as the Department of Defense, the National Science Foundation, the National Institutes of Health, the National Aeronautics and Space Administration and Department of Energy) are not related directly to the commercialization of technology, they have tended to subordinate industrially relevant initiatives. Formerly, the Office of Science and Technology Policy coordinated responsibility among these agencies to some extent, but it currently has neither the resources nor the inclination to play a strong role in this area. It is difficult to imagine that programs designed to support industrial technology will be elevated in status without some organizational change.

Second, technology programs that are industrially relevant are inadequately coordinated and implemented. Although individual programs are valuable, their overall effectiveness is hampered because they are spread throughout the government without viable mechanisms for coordination. Some constructive attempts have been made to address this problem. These include, principally, the National Science and Technology Policy Organization and Priorities Act of 1976 (PL94282), the Stevenson-Wydler Act of 1980 and the Technology Transfer Act of 1986. As discussed more fully in the following chapter, none of these laws has been implemented adequately. In part, this is a funding issue — for example, the Stevenson-Wydler Centers for Industrial Technology were never funded — but it is also an organizational problem. Unless policies have an institutional advocate committed to fulfilling their purposes over time, their goals are likely to remain unrealized.

Third, science and technology programs necessarily have long time horizons. Research results from particular projects often take years to achieve, and research in the future must be linked to work undertaken in the past. Similarly, industrial investments in the development of new technology need to be planned within a predictable financial climate. The current federal budget process often frustrates attempts in academe and industry to develop new technology. Annual appropriations decisions create significant discontinuities for many projects. Tax-law changes — particularly in the R&D tax credit, Treasury Regulation 1.861-8 and depreciation schedules — continually modify industry's cost picture for new technology. Congress must pay special attention to this problem, with strong consideration given to a longer budgeting cycle for scientific and technical programs.

Fourth, largely because of the federal government's traditional role as regulator, interactions between the public and private sectors have often been adversarial. Moreover, federal law has frequently discouraged cooperation within the private sector. In part, this has been changed by the 1984 antitrust modifications and new policies affecting cooperative agreements between industry and government. Although new partnerships are being formed between the private and public sectors and among private institutions, the pattern of a new, cooperative relationship is only beginning.

Cooperation between sectors has been made even more difficult because support for industrial technology has not been an explicit public mission. When government has supported industry, its contractors typically were seen as serving public purposes rather than *vice versa*. Perhaps even more important, there has been no established public forum where industry's needs could be considered, analyzed and acted upon.

Infrastructure

Public funds and government programs also play an important role in establishing the infrastructure for science and technology. On a fundamental level, federal programs affect the education and skills of the American work force. Although state and local government have the primary responsibility for education, federal spending constitutes about 10 percent of total education spending in the United States. The federal role consists principally of providing funds to support educational programs for the economically and physically disadvantaged. Federal funds also underwrite a number of special elementary and secondary programs, such as math and science education, and assure access to higher education by providing financial support to college students.

Outside the classroom, the federal government has a major impact on the funding of research, the establishment of technical standards and the demand for technical personnel. It funds about half of all basic research in higher education. The National Bureau of Standards establishes standards for materials. And the Department of Defense, the federal labs and other agencies are major employers of American scientific and engineering personnel.

The R&D Budget

Throughout most of the post-war era, the federal government has spent more each year on R&D than American industry. Today, government is responsible for about half of the nation's spending on R&D. In 1987, U.S.-based companies invested $61 billion in R&D; for FY 1988, Congress approved $61.1 billion in budget authority for federal government spending on R&D.

Most federal R&D spending is aimed at specific mission objectives — such as defense, health and space exploration — reflecting the public consensus for a strong federal role in these areas. Developing and applying new commercial technologies is the responsibility of the private sector. At the same time, however, it is widely recognized that U.S. government R&D spending has been used successfully to build the science and technology base of some important American industries, such as agriculture and computers, and that the governments of other industrial nations emphasize the commercial application of technology as an essential objective of their R&D programs.

R&D spending does not constitute a single funding category in the federal budget. Instead, it is distributed across several budget functions. The largest single category is national defense. In 1988, Congress approved $41 billion for defense R&D (about 67 percent of total government R&D spending) and $19 billion for non-defense R&D. Most increases under the current Administration have gone for military R&D, which has reached the highest funding levels since 1962. Non-defense R&D funding in constant 1982 dollars is lower today than at any time since 1966.

In absolute terms, the United States spends more on total R&D than Japan, West Germany, France and the United Kingdom combined and devotes the highest percentage of its gross national product to R&D (2.8 percent in 1987). (See *Figure 9.)* When defense-related R&D is excluded, however, a different picture emerges.

The United States devotes a smaller share of its R&D budget to non-defense projects than Japan, West Germany, France, the United Kingdom or Sweden. As a fraction of total GNP, total U.S. spending on non-defense R&D has stagnated at about 1.8 percent over the past 20 years, while the real cost of research has grown. In contrast, Japan's spending on non-defense R&D has grown to 2.8 percent of its GNP and West Germany's to 2.6 percent (see *Figure 10).* Furthermore, within the category of non-defense R&D, the United States spends the lowest proportion on R&D directly related to industrial growth.[2] The governments of other major industrialized nations place greater emphasis on focusing R&D efforts in areas believed to be important to economic development. One estimate suggests that, at most, only about 10 percent of federal R&D is relevant to the technical needs of industry.[3]

FIGURE 9

R&D EXPENDITURES AS A PERCENTAGE OF GNP
by country

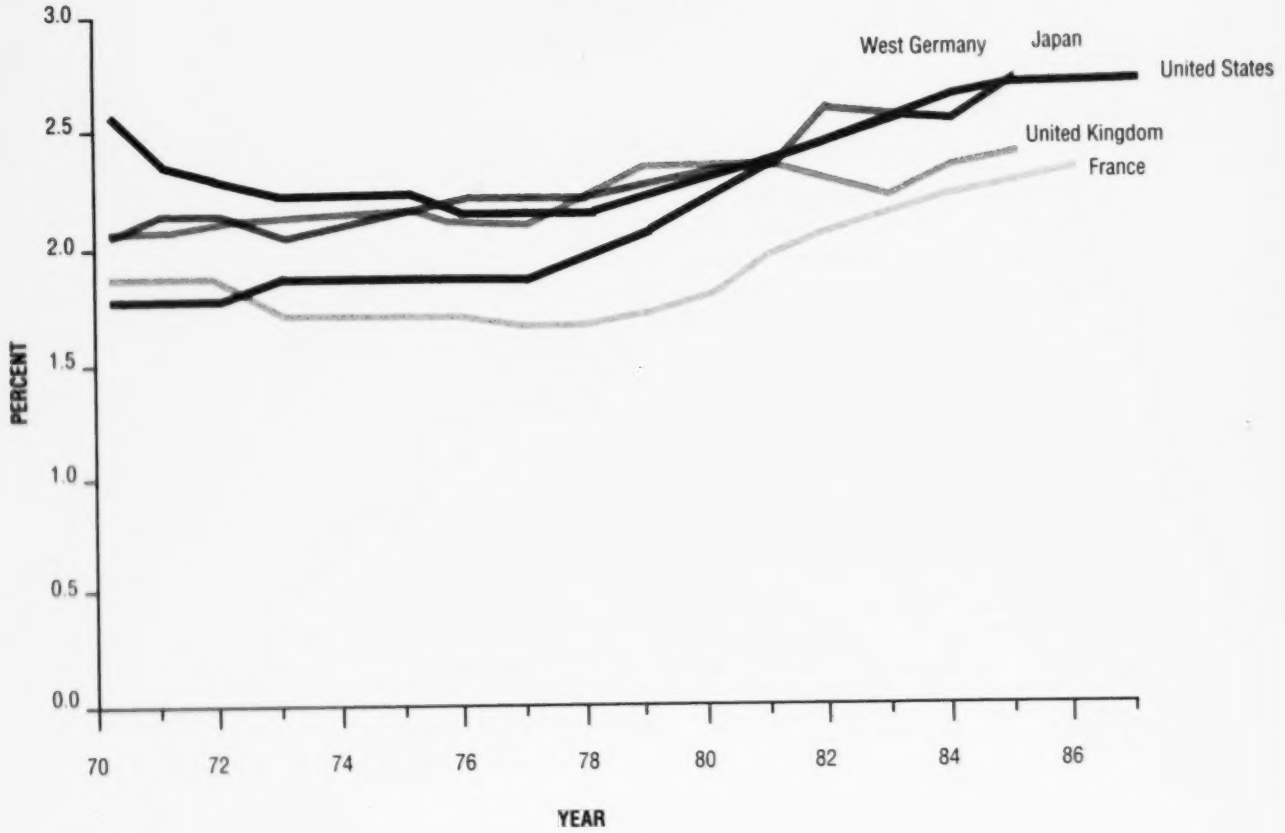
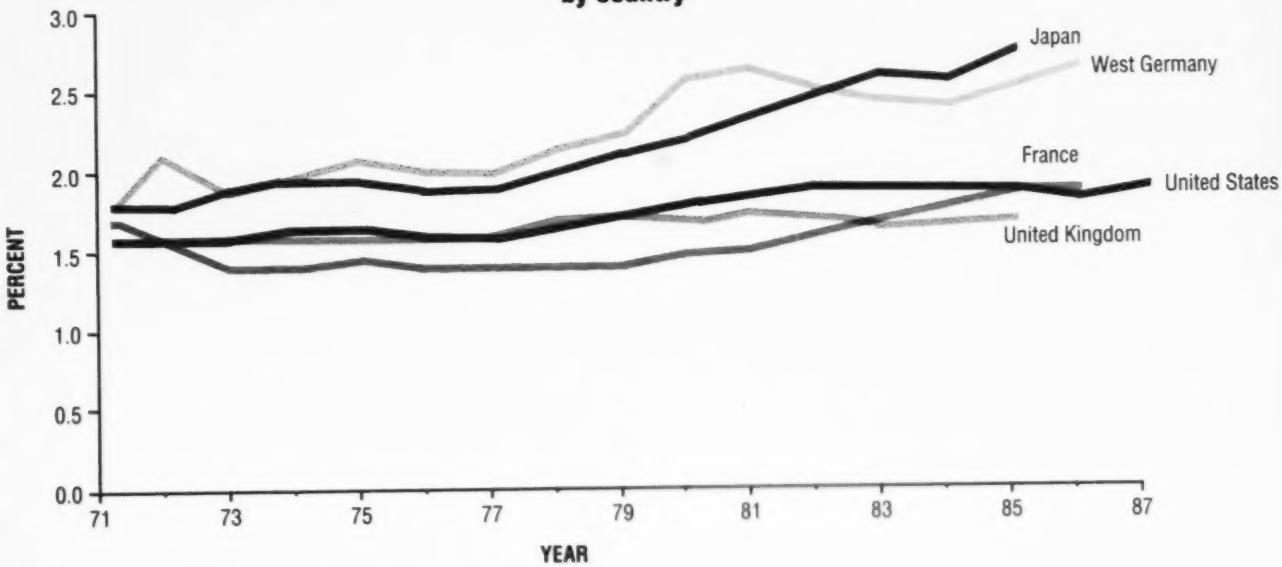


FIGURE 10

NON-DEFENSE R&D EXPENDITURES AS A PERCENT OF GNP
by country



Source: National Science Board, *Science and Engineering Indicators-1987*

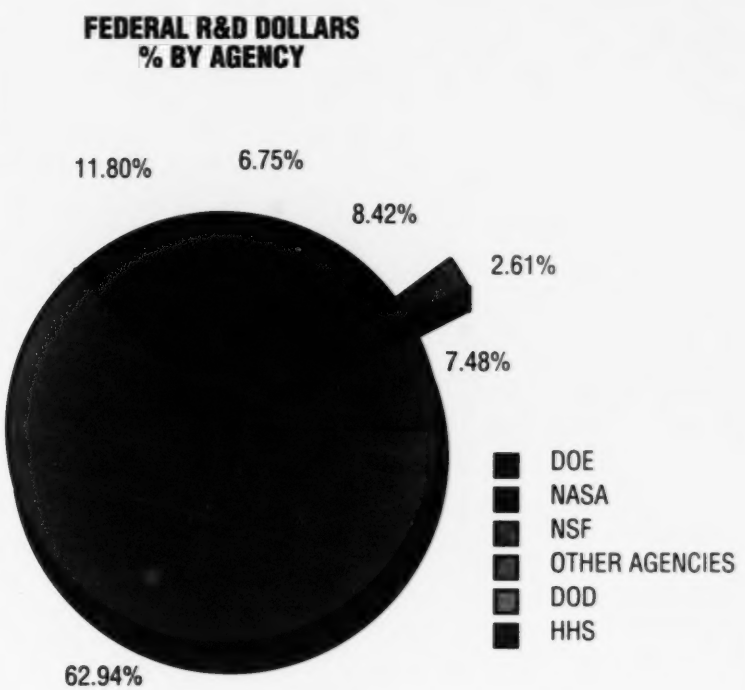
The top four U.S. non-defense R&D functions are health, space, general science and energy. The agencies responsible for these activities together account for more than three-fourths of total non-defense federal R&D spending. The remaining one-fourth is distributed over transportation, agriculture, natural resources, the environment and other areas (see *Figure 11*).

Since 1980, increases in federal R&D have been targeted on basic research, both defense- and non-defense related. Increases in non-defense basic research have been justified by the challenge of international competitiveness. However, the contribution of basic research to competitiveness is long-term, indirect and uncertain.

About 80 percent of federal non-defense R&D spending is concentrated on basic and applied research. Almost half of this spending goes for basic research, which represents a shift since 1976 when basic research was the smallest portion of non-defense R&D. In contrast, defense R&D is concentrated on development (about 90 percent). Defense basic research, which has declined despite the overall defense build-up, is far outweighed by basic research in other areas. In FY 1988, Congress approved $8.9 billion for basic research in non-defense areas, and $902 million for basic research in defense.

Despite the overall constraints on budget growth, major increases are being sought for such "big science" projects as the Strategic Defense Initiative, the space station and the superconducting

FIGURE 11



Source: National Science Foundation

super collider. These initiatives are very expensive, and any commercial benefits are not likely to be realized for long periods of time. Futhermore, these requests compete with federal funding for other R&D projects more directly linked to competitiveness and the overall health of the U.S. science and engineering infrastructure.

Government R&D Incentives

In addition to its own R&D spending, the federal government provides incentives for private sector R&D. Unfortunately, many of these incentives have been applied inconsistently. As a result, the objective of fostering private sector R&D has been undermined.

Beginning in 1981, a 25 percent R&D tax credit was enacted, whose value to industry was about $1.4 billion per year before it was modified to 20 percent in 1986. Since then, it has been extended, but not made permanent, disrupting industry's ability to plan long-term R&D projects. Because the credit is based on incremental increases in R&D spending, it can be claimed only for increases in company R&D spending over the prior three-year period. In 1986, Congress enacted the basic research tax credit, which encourages industry-sponsored university research. Like the R&D tax credit, the basic research tax credit has been enacted for only a short time period (1987-1989) despite the fact that basic research is, by definition, a long-term proposition.

In 1977, Treasury Regulation 1.861-8 was issued, which prevents U.S. companies with excess foreign tax credits on their overseas operations from deducting for U.S. tax purposes a portion of their domestic R&D expenditures. By increasing the effective rate of U.S. taxation on R&D, the regulation increases the cost of performing R&D in the United States and thus encourages American companies to shift their R&D overseas. Concern about the impact of Regulation 1.861-8 on U.S. competitiveness has prompted Congress to place moratoriums on its implementation four times without reaching a permanent solution. The last moratorium expired in 1987. Consequently this provision is currently applied to U.S. multinationals.

Outside of the tax context, reimbursement for independent R&D by Department of Defense and National Aeronautics and Space Administration procurement contracts amounted to about $3 billion in 1983. Another element of federal R&D support is the Small Business Innovation Research Program, which sets aside a percentage of federal lab contracting for small business. Agencies are required to advertise their needs and spend a minimum of 1.25 percent of their external R&D funds with small businesses.

The Federal Laboratory System

The federal government operates more than 700 laboratories established at various times for specific purposes. Over the years, they have expanded and diversified, partly because they succeeded in their original tasks, partly because their mission requirements were changed and partly because they are viewed as important to state economic development. Although the federal labs represent a significant portion of the nation's technical enterprise, supporting the commercial application of technology is not among their major priorities. Instead, they focus primarily on defense-related issues and basic research in specific areas, such as energy and health.

The role of the federal labs has evolved considerably over the past few decades. New concerns, such as space exploration, the energy crisis, cancer and AIDS have pushed them into new areas of research. Despite the valuable role they play in these areas, there is no consensus on their scope, mission and relevance to the nation over the next 20 years. Federal budget constraints and international competition in technology have raised serious questions about the labs' role and economic utility.

The debate about the federal labs' involvement in the commercial application of technology is complicated by political considerations, inadequate information about the scope and contribution of their research and disagreements about their appropriate role. As a result, it is difficult to coordinate their activities, much less to phase out those that have limited effectiveness.

Political considerations should not be underestimated. Many members of Congress view the labs as critical to their states' economies and as a source of high-technology jobs. Consequently, they resist any effort to close down or redirect lab resources, regardless of the performance of individual facilities.

In addition, because the lead agencies of the labs are mission oriented, they have a vested interest in maintaining control over the labs' research agendas.

A lack of reliable information further confuses the issue. In the aggregate, there is no question that the resources of the labs are immense. Their annual budget is approximately $20 billion, which is equal to almost one-third of the federal government's annual R&D expenditures and one-sixth of total national R&D expenditures. But it is difficult to determine exactly how many laboratories there are and how many scientists and engineers they employ, much less which institutions are effective in meeting their objectives and which should be reorganized for other purposes.

There are conflicting views about the role the labs should play in industrially relevant R&D. Some government and industry officials believe that a significant portion of the labs' research should be redirected to areas that are directly relevant to American industry. Proposals range from boosting technology-transfer initiatives to making the labs dependent on U.S. industry for a substantial part of their budget. This latter proposal would have the effect of creating a direct incentive for the labs to engage in more commercially relevant R&D; if they failed, their budget presumably would be cut back.

Others believe that the labs should not stray from their original mission objectives. Those who embrace this point of view stress that the commercial application of technology is, by definition, industry's responsibility. They maintain that even if the federal labs were directed to do so, they could make little contribution to commercial R&D. Instead of redirecting the labs to perform industrially relevant R&D, they argue, inefficient labs should be phased out and additional incentives provided directly to industry.

Despite these differing viewpoints, much of U.S. industry agrees that the labs need to be re-evaluated. Some labs need to be closed, others consolidated. For their part, officials from the federal labs criticize American industry for not making better use of the labs by keeping track of the research conducted there. They stress that foreign industry representatives regularly visit them to inquire about the status of research, while American industry rarely does so.

Recent federal initiatives — including funding of the Federal Laboratory Consortium, which works with a broad range of government agencies — have focused on technology transfer from the labs to industry. It is important to take advantage of existing legislation to make the transfer of useful technology work. In addition, however, it is important to address the need to refocus resources on research relevant to industrial needs.

The Regulatory and Legal Framework

If new technologies are to be commercialized successfully, they must overcome a set of economic, legal and regulatory barriers. These barriers arise from private agreements (such as contracts, licenses and corporate structures); from common law (tort and property concepts enforceable in court); and from public law and regulation. Just as the competitive context for American technology has changed enormously over the past decade, so, too, has the legal environment.

The effect of law and regulation on technological innovation cannot be characterized simply. They affect industries differently and often require amendment in the face of new technology and new markets. Some regulations are intended to encourage new technology — intellectual property rights being the prime example. Other regulations — pharmaceutical, pesticide and chemical registrations, for example — create deliberate barriers to ensure that new products are safe and environmentally sound. Yet even in this context, the government imprimatur can aid market acceptance.

Laws and regulations like these that directly affect technological innovation are only part of the problem. In fact, most laws and regulations are enacted to address a particular social issue that has little to do with technology. Although, in the aggregate, the impact of these laws and regulations on technology is enormous, it is almost entirely unmanaged — typically unforeseen by lawmakers, ill-considered by enforcement officials and often unpredictable.

Clearly, the legal and regulatory environment could be better planned and controlled. With foresight, laws and regulations could be designed to encourage technological innovation — or at least minimize negative impacts. This is not done, however, for several reasons: legislative ignorance of the issue; inadequate analytical resources to study the issue; an adversarial legal process that

impedes informal discussion; and the absence of a forum where industrial concerns can be aired. All of these deficiencies must be addressed in reformulating national technology policy.

The growth of government regulation

Federal regulation of industry today extends throughout the economy. The American penchant for making rules to guide the market, coupled with a reluctance to intervene in other ways, has caused the United States to be characterized as a "regulatory state." Other countries, notably Japan, take a different approach in which the state has taken on a "development" role, intervening more frequently to promote, rather than regulate, economic development.[4]

Indeed, a different approach was taken in America in earlier eras. Throughout the pre-Revolutionary period, for instance, the colonies saw themselves as promoters of economic growth. During the first hundred years of nationhood, the federal government dedicated itself largely to infrastructure development. During this era, the nation emerged as an exporter. The first regulatory agency, the Interstate Commerce Commission, was not established until 1887. Since then, laws and regulations have accumulated in waves: antitrust and trade laws at the turn of the century; labor and securities regulations in the 1930s; environmental and consumer-protection regulations throughout the 1970s. In recent years, the nation has imported massive amounts of goods and services and run up large trade deficits. It is important to shift the focus of national policy back toward facilitating exports.

The wave of consumer-protection legislation in the 1970s is perhaps the most problematic from the point of view of technological innovation. New and radically reformulated regulatory mandates arose: air pollution, water pollution, chemical registration, strengthened pesticide and pharmaceutical controls, equal employment opportunity, consumer financial protection, export controls, advertising limitations, and occupational safety and health. Ironically, this new wave of regulation was being enacted just as established regulatory regimes — such as trucking, natural gas and airlines — were being dismantled. The new regulations differed from the old not only in terms of their focus — consumer and environmental protection — but also in that their mandates typically were applied irrespective of industry boundaries. As a result, there was no way for regulators to consider the cumulative impact or to coordinate across regulatory regimes.

Developments in private legal practice intensified the regulatory changes ushered in during the 1970s. In some instances — environmental impact statements and civil rights, for example — legislative mandates opened the door to private civil actions that supplemented government enforcement. Elsewhere, the courts created major doctrines that enlarged consumers' and workers' rights and their ability to bring suit. An explosion of litigation, which has continued largely unabated through the 1980s, is most visible in the area of product liability.[5] A doctrinal movement away from fault-based torts to compensation in the absence of fault was accompanied by procedural innovations that allowed consumers to join in large-scale tort actions. Although product-liability reform has generated extensive discussion at the national level, by and large it has remained within the ambit of state law, and, thus, is highly variable across jurisdictions.

The regulatory process

Dramatic changes in administrative law and in the structure of private-public relationships also arose during the 1960s and 1970s. As a result, the American regulatory process has become more adversarial, political, legalistic and highly pluralistic. In part, these developments were fashioned by the courts, which transformed the Administrative Procedure Act into a powerful tool for challenging government action and ensuring public debate of regulatory decisions. Congress also chose to open government to the public through actions such as the Freedom of Information Act. This pluralism, while desirable, often has also caused uncertainty in the direction of public policy and has hampered the implementation of new policies and programs.[6]

Along the way, the regulatory decision process itself has become a subject of controversy. Since the Nixon Administration, each President has attempted changes, but only in the first four years of the Reagan Administration did "regulatory reform" become well-institutionalized. By and large, reform has not altered legislative mandates, nor has it eliminated many existing regulations. Instead, it has focused on how regulatory decisions are made, as expressed through four principal actions: paperwork reduction, as mandated by the 1980

Paperwork Reduction Act; economic impact analysis of major regulations, as mandated by Executive Order 12291; the establishment of a regulatory planning process, as mandated by Executive Order 12498; and executive oversight of the regulatory process through the Office of Management and Budget.[7] These initiatives in regulatory reform have primarily addressed economic regulations, with very little attention being given to social regulations in areas such as health, safety and the environment.

While valuable, these policies and procedures generally do not address issues pertaining to commercial technology. In a few specific instances, notably antitrust reform through the National Cooperative and Research Act of 1984, the promotion of new technology in industry was moved to center stage, but for the most part regulatory reform only considers technology within the generalized rubric of "economic impact." The indirect impacts of social regulations on technology development are significant in many industrial sectors and these regulations need review and streamlining. Nor does the reform process effectively attack institutional and organizational difficulties. For example, there is currently no neutral forum where industry can have its concerns about regulation and technology aired and discussed. Similarly, the ability to consider and coordinate the impact of regulatory requirements across different agencies and statutory mandates is inadequate. And few alternatives to adversarial regulatory procedures have been explored seriously.

Impacts on commercial technology

Laws and regulations have a pervasive impact on the process by which technology is introduced to the commercial marketplace. On the most micro-level, their impact is felt as products and processes are "engineered" to cope with applicable legal specifications. In the aggregate, they strongly shape the overall climate for technological innovation. The sheer breadth and variety of legal requirements make a full discussion here impractical, nor can simple conclusions be drawn. Nevertheless, a number of areas, discussed below, stand out as particularly important to the business community today.

Intellectual property rights are widely recognized as essential to technological innovation. Appreciation of this relationship has led to recent decisions strengthening these rights: the Supreme Court and Patent Office have upheld the patentability of life forms, patent-term restoration for pharmaceuticals and the right of government contractors to claim title to inventions.

At the same time, however, some industries face uncertainty about the extent of legal rights (for example, in the area of computer software).[8] In the context of government regulation, it is not clear that officials adequately protect trade secrets from disclosure to the public or competitors under the Freedom of Information Act. Perhaps the most pressing problems are in international markets where intellectual property "piracy" is common. The ability of foreign companies to legally "infringe" on U.S. process patents abroad has been a subject of legislative concern, and provisions to address this problem are included in the recently passed omnibus trade bill.

Direct restrictions on research are occasionally imposed by funding and regulatory agencies. Notably, genetic engineering experiments are subject to guidelines from the National Institutes of Health as a condition of funding, as well as regulations from the Environmental Protection Agency, the Department of Agriculture and other agencies. Similarly, new drug testing is subject to Food and Drug Administration controls on experimentation.

Pre-market and pre-manufacturing approval for new products moves government regulation beyond research into direct control of innovation. This occurs for pharmaceuticals, pesticides, food additives and industrial chemicals. The government's power to halt the marketing of a new technology, in turn, increases testing costs and delays. Although the need for these regulatory regimes is hard to question, there is also a need to strike a better balance between legitimate public health goals and the competitive position of the firms that produce new technology. Few legislative mandates have followed the lead of the Toxic Substances Control Act in this regard, which causes regulators to avoid "undue" adverse effects on innovation. Even the best legislative intent, however, can be frustrated by staff shortages in the regulatory agencies, an area of special concern today.

Restrictions on commercial transfers of technology occur mostly in the context of international sales, where concern for national security has led to a comprehensive system of export licenses

under the Export Administration Act. Controversy here centers not on the need for regulation, but on the details of implementation. This issue was addressed most recently in the omnibus trade bill when Congress attempted to better define strategic technologies subject to strict control and to streamline the administrative process.

Government standards also establish performance criteria for products and processes in commercial use — air pollution, water pollution, waste disposal, product safety and occupational safety and health are the main examples. These standards influence technology in diverse ways. For example, because new sources typically are treated more strictly than old ones, some bias against modernization may arise. On the other hand, the regulations that mandate use of "best available technology" encourage diffusion of new techniques to lagging firms. Because environmental and safety standards have such significant economic impact, their costs and benefits are carefully weighed in rulemaking. Nevertheless, the analysis typically pays insufficient attention to the affect on commercial technology. In addition, because the rulemaking process is so lengthy, subsequent changes to adapt to new technical developments are made with difficulty. Greater use of informal consultation or negotiating strategies between industry and regulators may be useful in remedying these problems.

State product-liability laws also significantly influence the development of technology. Here, the laws are problematic because they cut two ways. On the one hand, high insurance and liability risks now associated with untried products deter the introduction of new technology. On the other hand, court awards made against old, unsafe products make it imperative to introduce improvements or substitutes. Because liability is imposed *ex post facto*, and is based on ever-evolving precedents, the law is also highly uncertain. Reform efforts therefore have focused on means of creating a more predictable legal environment. For the most part, these actions have occurred at the state level; Congress has been reluctant to enter this traditional area of state jurisdiction.

Evaluating the impact of regulation

The precise impact that the legal and regulatory environment has on technology is extremely difficult to assess. Analysis is hampered by methodological problems, lack of appropriate data and disagreement about evaluation. Perhaps the most troublesome issue is that the analysis can only be done in the particular: each regulation is different; each industry's technology is different; and each company will have different responses.

While the impact of regulation is specific to industries and companies, regulatory decision-making is oriented toward broad problems that span industries. Discontinuity and controversies emerge as regulatory and legal mandates are applied without a unified perspective. Nowhere has this been more evident than in the biotechnology industry.

Biotechnology research has long been supported by the National Institutes of Health and the Department of Agriculture, both of which have been thrust into a regulatory role. In addition, the Environmental Protection Agency (under both pesticide and toxic substances authority), the Food and Drug Administration and the Occupational Safety and Health Administration all exercise regulatory control over certain aspects of biotechnology. Environmental impact litigation has cast the judiciary as a major player as well.

At least two fundamental problems have arisen in this regulatory scenario. First, the overlap among the regulatory agencies, their many scientific advisory committees, Congress and the courts has created a highly inefficient, often confusing and conflicting system. These difficulties have not been addressed adequately by attempts at coordination at higher levels (for example, the Biotechnology Science Coordinating Committee). Second, the current institutional structure lacks a forum for overall consideration of the balance that needs to be struck among the competitive position of this industry, the development of its technology, and public health and safety.

Reforming the legal and regulatory system

The regulatory and legal apparatus represents the accumulation of many years of federal activity. Throughout its history, America was responding to diverse sets of pressing social issues, as has been discussed earlier. By and large, however, today's laws and regulations were enacted during a period when the United States was more insulated from the international economy, and the competitiveness of American industry was a matter of little concern.

The changed competitive circumstances now demand reforms in the regulations and laws to harmonize their legitimate objectives with a new national economic agenda.

Regulatory and legal reform should be directed toward four broad goals. First, changes need to be made in obsolete legal structures. Inadequate protection against international intellectual property piracy and tax provisions that discriminate against domestic R&D investments are priority issues. Second, more consideration needs to be given to the potential negative impact of certain regulatory measures. Restrictions on international transfers of technology and slow or overly strict new product-approval procedures (for example, in pharmaceuticals) may present the most pressing problems of this nature. Third, the promotion of technology must become an integral element in regulatory strategies. Regulators must consider explicitly the impacts of their actions on the development of new technology, and, to the extent possible, craft regulations that encourage technological innovation. All legal and regulatory regimes need to reflect this orientation. Fourth, better mechanisms of coordination, analysis of industry impacts and consideration of the technological dimension of law and regulation must be developed.

These goals can be accomplished through various legislative, administrative and private sector initiatives. Specific amendments to the legal and regulatory systems need to be considered along with enabling statutes on a general "technology mission." The novel decision-making criterion in the Toxic Substances Control Act — to minimize undue impacts on innovation — may provide a model.

Inside Executive Branch agencies, analyses of the impacts of regulation on technology must become more important. Regulatory strategies that promote innovation in industry must be considered. These objectives could be added to the existing analytical requirements contained in Executive Order 12291 or they could become a separate, complementary analytical effort.

New institutional mechanisms may be necessary to build a technology focus into law and regulation. It also may be desirable to change the skill mix and orientation within the federal regulatory apparatus, which is currently dominated by lawyers and economists. More technically trained individuals are needed, perhaps drawn from industry on a temporary basis. Last, coordination of regulation needs to be made a high-level, high-priority concern.

During the 1980s, the federal government has initiated a number of promising pro-technology initiatives. All too often, however, these policies were piecemeal, *ad hoc* and inconsistent. In some cases, promising new laws were enacted, but never funded. In other cases, a benefit bestowed by one Congress — the R&D tax credit, for instance — was denied by the next. Chapter 4 assesses new developments in U.S. technology policy at both the federal and state levels, initiatives that help set the stage for a series of recommendations.

Endnotes

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CHAPTER IV
NEW DEVELOPMENTS IN U.S. TECHNOLOGY POLICY

As a result of the reevaluation of its traditional role in science and technology, the U.S. government is becoming more involved, on a selective basis, in aiding the private sector's commercial application of technology. During the 1980s, Congress and the Executive Branch undertook a number of important new initiatives, in large part motivated by growing concern about faltering commercialization. In general, these appear to have been positive steps. In some cases, it is too early to judge the results and, in other areas, programs have been underfunded.

Recent Federal Initiatives

- A first important action occurred in the fall of 1980 when Congress passed the Stevenson-Wydler Technology Innovation Act and committed the country to broad support of technological innovation. The bill prescribed some organizational changes to focus the Executive Branch (principally the Department of Commerce) more clearly on industrial technology by mandating a government-wide program of technology transfer and authorizing a network of centers for industrial technology. Because the Stevenson-Wydler Act has never been fully implemented (the Centers for Industrial Technology were never funded, for example), subsequent legislation has been used to fulfill specific aspects of its vision.

Several bills focused on intellectual property: the Bayh-Dole Act, the Patent Term Restoration Act and the Semiconductor Chip Protection Act. All of these attempted to broaden the legal protection for inventors by, respectively, allowing federal contractors to claim title to inventions, restoring the patent term for pharmaceuticals to the extent that it was shortened due to regulatory review, and

establishing a new form of intellectual property rights for chips.

Other legislation specifically addressed the operation of federal R&D programs. For example, in 1985 the National Science Foundation charter was amended to give engineering a stronger role. Furthermore, the Small Business Innovation Research program phased in mandated increases in federal R&D contracting with small business. In addition, the Technology Transfer Act of 1986 and Executive Order 12591 established a system of cooperative agreements and sought to increase technology transfer between the labs and private firms by giving financial incentives to federal employees, among other measures. This legislation, however, has only been partly implemented. The emphasis on cooperative modes of technology development and transfer was strengthened by National Science Foundation programs to establish university-industry cooperative research centers. Building on the successful experience of its Engineering Research Centers, the National Science Foundation has attempted to establish interdisciplinary Science and Technology Centers, which are still in the planning stage. The participation of industry in the research program has influenced the content of the research agendas and stimulated a renewed focus on manufacturing.

A noteworthy event occurred late in 1987, when Congress appropriated $100 million of Department of Defense funds in fiscal 1988 for Sematech, a research consortium recently formed in the semiconductor industry to counter intense competition from overseas manufacturers. Sematech's goal is to develop manufacturing technology for a new generation of integrated circuits.

The U.S. machine tool industry also is involved in a national effort — the National Center for Manufacturing Sciences — to explore new developments in manufacturing. It expects to spend approximately $30 million over three years, with half of the money coming from industry and half from the government. As with Sematech, the Department of Defense will help fund this effort.

These two initiatives demonstrate that growing concern about U.S. industrial competitiveness is prompting the federal government to focus on the commercial application of technology. They also indicate the Pentagon's increasing concern about the ability of American industry to support technology-related national defense requirements. The Department of Defense has launched the Industrial Base Initiative to identify and encourage critical manufacturing capabilities of U.S. industry.

Other federal initiatives have attacked regulatory and international issues. The National Cooperative Research Act of 1984, which relaxed the antitrust laws for research consortia, is particularly noteworthy. In 1986, the Export Administration Act was amended in response to business concern about the impact of export regulations on international competitiveness. And in 1987, Congress passed the Japan Technical Literature Act, which mandated a program of assessment, translation and dissemination of Japanese-language sources by the Department of Commerce.

Few of these initiatives required major new appropriations by the Congress, which made them especially attractive in a period of fiscal stringency. Even so, science and technology funding programs tended to fare well. Research support grew 26 percent in real terms between 1980 and 1985, primarily in defense and basic research. In the 1986 Tax Act, the R&D credit was one of the few benefits preserved, albeit at a less generous level than before.

The technology policy issue receiving perhaps the most attention and the least action within the last several years is the organization of the federal science and technology policy apparatus. A number of recommendations have been advanced in an attempt to incorporate a concern for commercial technology more clearly in the organization of the federal government. The broad contours of these proposals are:

- **Enhanced Office of Science and Technology Policy.** Expanding the functions and capabilities of the office could strengthen the federal focus on industrial technology. An important part of the work would be to improve the funding and implementation of existing technology-related policies and to spur greater coordination among federal science and technology agencies. With direct access to the President, the office could become more active in budget and oversight matters, functioning as an advocate for industrial technology at the highest levels of government. In theory, the office already has many of these functions, but

its lack of authority over other agencies, small budget, lack of staff and inevitable preoccupation with day-to-day Executive-Office concerns limit its effectiveness.

- **Policy and Technology Foundation.** A National Policy and Technology Foundation, patterned after the National Science Foundation, would fund civilian industrial technology as one of its main purposes. This option represents the institutionalization of initiatives such as congressional funding for Sematech. The new foundation would identify critical industrial technologies, fund the relevant industries and provide a forum for analyzing important issues relating to civilian technology.

- **Department of Science and Technology.** This option, recommended by the President's Commission on Industrial Competitiveness, would consolidate many of the science and technology support programs into a single Cabinet-level department. Such an agency could coordinate existing programs, reallocate budget and possibly reorient the work of certain federal laboratories. However, such an agency could bring with it over centralization and bureaucracy, and weaken useful rivalry and experimentation among existing programs.

- **Department of Technology.** A Department of Technology also would function at the Cabinet level, but would limit itself to activities and programs related to industrial technology. No basic research programs would be included. New analytical missions relevant to international competitiveness might be added and the new department possibly would have funding authority to directly support industrial technology development in appropriate circumstances. Two quite disparate versions have been discussed. One would pull together all technology programs not related to defense; the other would unite only those technology programs with missions related to industrial competitiveness.

- **National Institute of Industrial Technology.** A smaller-scale alternative to a Department of Technology, the Institute would be built around the National Bureau of Standards and primarily would provide technical services to industry. It might be involved mainly with establishing and funding regional or state centers that undertake cooperative research or provide technical services directly to private firms. A variant of this option is a civilian version of the Defense Advanced Research Program Administration.

- **Technology and Science Advisory Councils.** Irrespective of the form reorganization takes, a technology policy advisory body could be a useful adjunct (although not an alternative) to a new technology and science agency. One option would be to constitute a council that would include the heads of the major science and technology agencies that could function like the Economic Policy Council and provide direction on major decisions dealing with technology. Alternatively, a group of leading industrial figures could advise a new technology and science agency.

The multiple initiatives of the 1980s demonstrate the growing concern about U.S. competitiveness and acknowledge the critical role of technology. In many respects, these initiatives have focused on the critical issues in the commercialization process: cooperative R&D, intellectual property, regulatory constraints, technology transfer, generic manufacturing and government organization.

Yet, little has changed. The government policy-making apparatus remains fragmented. Implementation of new legislation has been a recurrent problem. In some cases, promising new laws were enacted but never funded. In others, bureaucrats and program administrators could not accommodate new priorities rapidly, and a shortage of skilled staff slowed progress. In still others, political considerations came into play: a benefit bestowed by one Congress, for example, was undercut by the next. Throughout the government, there remains far too little coordination within the federal bureaucracy and among the federal agencies, the states and private sector.

State Technology Programs

Justice Louis Brandeis remarked some 50 years ago that one of the "happy incidents" of the

American federal system was the ability of states to serve as "laboratories" for social and economic experiments.[1] Often, this has meant that ideas are originated among the states and then emulated at the national level. It also has meant that states sometimes carry out programs funded in Washington. The outstanding example is the agricultural extension service. Here, the federal government contributes financial and administrative resources, but wisely chooses to leave implementation in the hands of states and universities, which have both expertise and proximity to the program's clients — the nation's farmers.

During periods of federal quiescence in a particular policy area, state activity often becomes intense. This appears to be true in the area of economic and technology development. An active state role took root first in regions adversely affected by plant closings and changes in the traditional nature of their economies — mostly the northeast and north-central states. Until the 1970s, the overriding goal was to attract business, with tax incentives being the main tool. Later, job-retention measures — subsidies, plant-closing legislation and regeneration of mature industries through new technology — were added.[2]

Focus on technology

By the early 1980s, the goal of state programs oriented toward economic development had taken on a very different cast: creation or expansion of business enterprise through new and improved products, services and technology.[3] Although earlier concerns were not abandoned, the promotion of technology or technology-oriented businesses moved to center stage. Southern and western states, whose resource-based economies had suffered reverses, embarked on active technology-development programs along with northern and eastern states.

By mid-1987, the National Governors' Association reported that 31 states had offices responsible for promoting the growth of technology-based businesses and most other states provided assistance through state university systems or economic development authorities.[4] More than 500 discrete programs have been identified, but, given the intense interest in this area, additions and changes make such numbers obsolete almost as fast as they are tallied. As recently as May of 1988, for example, Alaska had established its own state science and technology foundation.

Many factors fueled the growth of state technology-support programs. Fundamentally, the states recognize that technology is ever more critical to the long-term growth and competitiveness of every region of the country. Beyond this, state officials appreciate keenly the fact that technology development is anchored in local and regional conditions. Lastly, state action was often necessary in order to counteract a declining federal presence.

Despite the soundness of the underlying concept, many technology-oriented programs were marred initially by over-enthusiasm, loose conceptualization and, predictably, frustrated expectations. In particular, the widespread emphasis on a few "high-technology" sectors overestimated the contribution of high-technology to employment growth and ignored the potential gains from improvements in traditional technical areas.[5] In addition, programs tended to assume that three models — Massachusetts' Route 128, California's Silicon Valley and North Carolina's Research Triangle Park — could be duplicated widely. These enormously appealing complexes did, in fact, show similarities: successful incubation of a high-technology complex over a long period, close university-industry relationships and ample federal money. On the other hand, each had unique aspects that were not applicable elsewhere. Moreover, in each case the early stages of development were accomplished with minimal state involvement; state support grew only when the complexes had the look of success.

Characteristics of state programs

Today, state technology programs have matured and are highly diverse and sophisticated. In any given state, a wide variety of initiatives may exist, carefully tailored to the strengths and needs of the local economy. In fact, it is almost misleading to characterize them as government programs, because the private sector has often taken the lead, private or quasi-public entities frequently carry out the initiatives and university activities play a vital role. The most common initiatives can be grouped into five categories: 1) centers of excellence; 2) venture capital for new products or technologies; 3) incubators to support entrepreneurs; 4) intermediary partnerships; and 5) information dissemination.

Centers of excellence are partnerships between state officials and higher education institutions that concentrate academic activity on technical areas the state can exploit as a unique competitive advantage. Typically, faculty members receive funding for research in areas that are likely to lead to commercially viable ideas, attract industry for collaborative research or help start new companies. Existing companies form affiliations with the center, cooperating in research projects and providing matching funds. Centers of excellence have become popular within the last several years. Ohio alone has 10, for example. Some are similar to the National Science Foundation's engineering research centers, raising concerns about duplication and destructive competition.

Venture-capital programs provide equity or loan financing to support R&D or the development of innovative products and services. Examples include the Indiana Corporation for Innovation Development, the Massachusetts Technology Development Corporation and the New York Corporation for Innovation Development. These state-funded independent corporations function much as private venture capital companies would and, indeed, are often co-founders with private sources. Their special focus, however, is on new technologies or products that offer significant potential to the state economy but that carry high enough risks to make conventional sources of financing unavailable or inadequate. Technical, management or other consultation services also may be offered in conjunction with financing.

The recognition that financing is only one of the entrepreneurs' needs has prompted the creation of a number of outreach programs. Often called incubators, these initiatives may furnish new companies with low-rent office space, aid in developing business plans or undertake specific applied research projects, typically through a state university. Georgia Tech, for example, has such a program, and the University of Maryland has a technical extension service targeted at manufacturing firms. Business counseling and technical advice form a large part of the attempt to "nurture" entrepreneurs in these programs, making them perhaps the most hands-on and varied of technology-support endeavors.

Intermediary partnerships is the term often used to describe the combination of various types of programs — grants, applied research, venture capital and information dissemination — that have been grouped under one organization. Created as private, non-profit organizations encompassing business, labor, education and non-profit groups, the partnerships receive state financial support that they leverage with outside funds solicited on a project basis. Examples include Pennsylvania's Ben Franklin Partnerships, Arkansas' Science and Technology Authority and Tennessee's Technology Corridor Foundation. The purpose of the partnerships is to create an integrated, coherent set of activities to support technology and entrepreneurship. Typically decentralized, partnerships work closely with local groups: labor unions, universities, economic development agencies, large companies and entrepreneurs. Nevertheless, they appear to be increasingly important and may play the leading role in state technology development in the future. They provide a radically different organizational paradigm than the state bureaucracies that have been dominant in the past.

Information-dissemination programs, the last type of state effort, have long been a university-based, state-funded effort. These programs are designed to enable companies to stay current in a particular technical area or to collect literature and data relevant to a firm's needs. Although information dissemination obviously can be linked with the other types of programs, many are more passive and reactive and may be restricted from direct involvement with technology transfer.

Three examples: California, Pennsylvania and Ohio

By most measures, California ranks as the nation's high-technology leader. It places first in high-technology employment, R&D expenditures and receipt of federal R&D monies. In large part, this springs from a unique entrepreneurial culture, strong university-industry links and federal support, not from state government action. Nevertheless, California certainly owes its success in part to its traditional leadership in the area that states increasingly consider the single most important contributor to technology and economic growth: quality education.

During the 1960s and 1970s, California's economic policy lacked an explicit focus on technology. In the mid-1970s, however, Governor Jerry

Brown formed the California Commission on Industrial Innovation, which outlined a strategy to promote technological innovation that is perhaps more comprehensive than any other state's. Programs such as MICRO, which provides matching grants for industry support of University of California microelectronics projects, grew out of the commission. In contrast, Governor George Deukmejian's current approach has emphasized economic development more generally and a less active role for government. Many of the commission's recommendations have therefore been dropped. California does not have a state office of science and technology, but houses a number of technically oriented programs, particularly for small business, in its Department of Commerce.

Pennsylvania provides a prototype for states with severe economic problems due to a dramatic erosion of their traditional industrial bases within a relatively short period. In the face of plant closings, the state developed a set of technology-development-support programs that are among the most coherent and active in the country. Preeminent among them is the Ben Franklin Partnership Program, begun in 1982, which operates four advanced technology-development centers in different regions of the state. These centers provide applied research funding, entrepreneurial assistance, education and training, and seed capital. Their intention is to link private and academic resources, to make traditional industry more competitive and to spin off new businesses from universities. By most accounts, the Pennsylvania program is the largest in the country and is generally credited with much success.[6]

Ohio's economy is similar to Pennsylvania's. In 1983, Ohio initiated a program named the Thomas Alva Edison Partnership program, which at first glance seems to be an imitation of Pennsylvania's Ben Franklin Partnership program. In fact, the programs are quite different.

The Edison program is operated by the Ohio Department of Development and has an advisory board appointed by the governor. The program has three separate initiatives: the Advanced Technology Application Centers, the Innovation Research Financing Program and the Search for Innovation Technology Program. The first two are research and development programs; the Search program is a technology brokering/transfer activity. Total funding for the Edison program from 1983 to 1985 was $32.4 million; for 1985 to 1987, it was $34.8 million.

Over two-thirds of the budget is used to provide matching support for the Advanced Technology Application Centers. Six of these centers have been established at universities. They focus on generic technology research in areas such as advanced manufacturing, polymers, biotechnology and information technology. They are expected to attain national or international leadership in their respective fields, and are required to emphasize technology transfer to the private sector and to demonstrate how jobs can be created in Ohio. Estimates of the total matching fund commitment from non-state sources ranges from $75 million to $127 million.

Ohio's program is too new to evaluate meaningfully, but the state and matching funds that have been committed are encouraging signs. A technology-research-center approach on the scale of Ohio's can strengthen universities, but it does not solve the immediate need to create and retain jobs through applied research and to train workers for these jobs. Even though technology transfer has been emphasized, concrete results from the Edison Technology Centers in the form of products and jobs are likely to be realized only in the medium- to long-term.[7]

Assessment of state efforts

State technology-development efforts are not quick fixes for economic problems. Typically modest in scope, they must be viewed as only one part of a very long-term strategy to invest in and renew state or regional economies. Private sector and federal initiatives almost certainly have been more important. The successful high-technology complexes — Route 128, Silicon Valley, Research Triangle Park — took many years to develop. And successful individual projects may easily take five to ten years to mature into commercial results. Programmatic undertakings, at either the state or federal level, therefore must provide long-term, consistent and patient support, concentrating on building institutions and affiliations as well as projects with particular objectives.

The realization that infrastructure, not projects, is the most important element of success has led many states to emphasize education as the single most critical element in state technology-development strategies. One widely shared

assumption is that future technology development will depend more and more on close ties between industry and higher education institutions. This has prompted efforts to develop new university-industry relations. Faculties and university administrators have responded with alacrity. Universities also are encouraged to play a larger role in entrepreneurship, as a source of both spin-off businesses and of advice to the private sector. Clearly less-emphasized but not ignored, training and technical skills development for workers also has been the subject of some programs. In addition, efforts are under way across the country to improve science and mathematics education at lower grade levels.

State programs uniformly recognize the need for the private sector to take the lead. Today, in contrast to earlier economic-development efforts, government's efforts are designed to help, rather than guide. Public programs are seen more as accelerators than initiators of industrial change. Moreover, independent, non-profit, non-governmental institutions are clearly preferred to a government agency as the focus of technology-development efforts.

State programs have recognized that a single element, such as funding or technical information, is insufficient. Instead, most states employ the entire range of activities related to commercialization, from research to business-plan development. The fact that technology programs are commonly part of overall economic-development plans underscores the appreciation of the government-business-academe links necessary for successful commercialization.

The wide variety of state programs attests to the fact that the promotion of innovation is a pragmatic, non-doctrinaire activity. No single model is best or suitable for all circumstances. The orientation must be local: entrepreneurs, workers and researchers must come together at a local site. Typically, technology is adapted first for use in local markets. Programs therefore need to be highly decentralized, flexible and able to respond to changing economic conditions.

Although, in the aggregate, state programs represent a large investment in innovation, most individual efforts are quite small. (Exceptions include Pennsylvania, which spent about $500 million last year, and Virginia, which spent $86 million.) Because state governments rarely have generous resources, administrators must leverage what they receive. The virtues mentioned above — cooperation across sectors, joint funding, flexibility — are virtues born of necessity as much as they are a conscious choice.

Last, the state programs provide some lessons about what not to do. By and large, they show that focus on research, particularly basic or academic research, holds little promise as a technology-development strategy. Nor will it appeal politically to the legislature that must provide funding. State programs are also recognizing that "high-technology" provides no panacea — and may even be a counterproductive strategy. The most fruitful efforts are geared to exploiting the potential and renewing the strengths, often traditional in nature, of the local economy.

Federal-state linkages

The relationship between the states and the federal government must be determined by the kinds of functions each can best fulfill. By and large, the federal government does better with funding programs and with large-scale projects and institutions. The states function more effectively at the grass-roots level with activities oriented toward particular ventures. A guiding principle of the federal-state relationship should be for each to acknowledge the other's area of competence.

Although the benefits of coordination are obvious, it is not always easy to achieve. The federal government, principally through the National Science Foundation's advanced scientific computing centers, engineering centers, and science and technology centers, is embarking on programs that closely resemble what states have been doing in their centers of excellence. State officials believe that their federal counterparts have not always been sensitive to the need to coordinate the ongoing state initiatives with new federal undertakings. And there is a great need for information transfer and coordination between the two levels of government.

The first step toward better coordination is to develop a better information base about state programs. This need was recognized in the Bumpers provision in the omnibus trade bill, which mandates a survey of state technology-support programs and provides for a federal information clearinghouse in the Department of Commerce. Funds for these programs have been included in

FY 1988 and FY 1989 appropriations bills.

The most immediate source of support that the federal government could offer state technical programs comes from the federal labs. Through cooperative agreements, the labs could provide financial, technical or personnel support to state programs. Further, the labs might be directed by legislation to devote a certain portion of their resources to local technology-development efforts.

The federal government also could provide direct financial support to state programs. In fact, there is already legislation, the State Technical Services Act of 1965, that commits the federal government to do so. This Act, which has gone unfunded since its passage, could provide the basis for federal support.

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CHAPTER V
RECOMMENDATIONS

In supporting and encouraging private sector efforts to commercialize technology, the federal government has four responsibilities: bolstering the macroeconomic environment with fiscal, monetary and trade policies that foster international competitiveness; establishing policies that encourage, not hinder, the development of new technology while improving the machinery for making technology policy; strengthening the technology infrastructure; and expanding national R&D efforts.

A unifying theme in this report's recommendations is the basic need to place competitiveness at the top of the national agenda and to recognize that the ability of American firms to commercialize technology effectively has a crucial impact on their ability to compete in world markets. The Council's recommendations should be viewed as essential first steps. By themselves, they will not solve the commercialization problem. They can, however, set the stage for private sector success.

RECOMMENDATION 1: THE FEDERAL GOVERNMENT SHOULD IMPROVE THE MACROECONOMIC ENVIRONMENT THAT AFFECTS THE PRIVATE SECTOR'S ABILITY TO DEVELOP AND APPLY TECHNOLOGY.

Without appropriate macroeconomic policies, it will be difficult for U.S. firms to meet the international challenge to American innovation, even if government science and technology policies support their efforts. Two issues in particular need to be addressed: the federal budget deficit and U.S. trade policy.

Make fiscal policy more supportive of private sector efforts to commercialize technology. U.S. fiscal policy — including large federal budget deficits and the tax structure — affects the supply and cost of capital to American industry, which has an important impact on private sector efforts to

commercialize new technology. Credible multi-year deficit reduction should be a top priority of the new President and Congress. Furthermore, tax policy should be structured to promote savings and long-term investment.

Strengthen U.S. trade policy for technology. The development and application of new technology also is influenced by trade policy. Restricted access to foreign markets, foreign targeting of high-technology industries and violations of intellectual property rights all serve as disincentives for U.S. firms to design and introduce new products into the marketplace. The omnibus trade bill contains a number of provisions designed to better protect U.S. industry against unfair trade practices. The Council believes that the Administration should use these new tools to improve market access for U.S. high-technology products, to protect U.S. firms and workers from the potentially negative effects of foreign targeting policies and to improve protection of intellectual property. The creation of a new unit within the Office of the U.S. Trade Representative that focuses on science and technology, intellectual property, services and investment is a step in the right direction.

RECOMMENDATION 2: THE FEDERAL GOVERNMENT SHOULD IMPROVE THE MACHINERY FOR MAKING TECHNOLOGY POLICY.

The President and Congress should refocus the federal science and technology policy apparatus to give more weight to issues related to the commercial application of technology; to strengthen the funding and stature of federal R&D programs that contribute to industrial competitiveness; and to create a more hospitable legal and regulatory environment for the commercial application of technology.

Appoint an Assistant to the President for Science and Technology. To ensure that the commercial application of technology remains a priority issue, the next President should elevate the position of National Science Adviser to that of Assistant to the President for Science and Technology. Like the current National Science Adviser, the Assistant to the President would serve as the head of the Office of Science and Technology Policy, but would have more input into policy decisions. To be effective, the Assistant to the President must have the full support of the President. The National Science Adviser currently reports to the White House Chief of Staff, and is not a member of the Cabinet or the Economic Policy Council. The Assistant to the President should report directly to the President, have Cabinet-level status and be an active member of inter-agency groups such as the Economic Policy Council and the National Security Council.

Because of the interrelated nature of technology and science, the Assistant to the President should be responsible for both areas, with the clear understanding that progress in science alone is not enough to meet international competitive challenges and that the government must systematically aid private sector efforts to identify, develop and deploy technology. Elevation of the position of Assistant to the President would not entail the creation of a new agency. The Assistant to the President should be provided with sufficient staff and resources to discharge his responsibilities effectively. Additional responsibilities of this position are outlined below.

- **Be a vital participant in shaping the macroeconomic and regulatory framework that affects the commercialization of technology.** The Assistant to the President should participate fully in the formulation of macroeconomic policy. He should make sure that technology issues are carefully considered in these discussions and not treated as residual or secondary concerns.

- **Develop priorities and coordinate science and technology policy across agencies.** The Assistant to the President should help develop overall priorities and take them to the President for approval. He should also coordinate science and technology policy. This effort should include a review of the programs and objectives of individual science and technology agencies to ensure that they are consistent with one another and that they facilitate the commercial application of technology.

- **Review the federal science and technology budget with the Office of Management and Budget.** Nowhere in the federal budget-making

process is there an evaluation of the total federal science and technology budget and its rationale in terms of national goals. The Assistant to the President should be responsible for a cross-cutting review of the overall science and technology budget, looking beyond individual agencies' missions to consider whether the aggregate science and technology budget contributes to U.S. competitiveness.

- **Monitor implementation of policy.** Much of the legislation necessary for a more effective government focus on technology is already on the books, but has not been effectively implemented. The Assistant to the President should monitor the efforts of government departments to implement these policies and bring to the President's attention failures of implementation. The Assistant to the President should work with Executive Branch agencies and Congress to make sure that key initiatives are fully implemented.

- **Work with the Office of Management and Budget's Office of Information and Regulatory Affairs.** The Assistant to the President should work closely with this office to ensure that the current regulatory framework, to the maximum extent possible, supports private sector efforts to commercialize technology. Among the issues that should be considered are export controls, procurement and reimbursement policies, standards and testing requirements, product- and plant-approval processes, reassessment of laws and regulations that hinder or slow the commercialization of technology, and ownership of data rights.

- **Develop a four-year President's strategy for science and technology.** The Assistant to the President should work with the President, the Congress and the relevant Executive Branch agencies, and consult with leaders from the private sector to develop an overall Administration strategy for science and technology. This strategy should be developed early in the new Administration's first year in office. It should be presented to the relevant committees in the House and Senate, made available to the American public and updated as necessary during the Administration's term in office. At present, Congress and the Executive Branch consider science and technology issues on a piecemeal basis. Priorities are not ranked and, as a result, programs compete counterproductively with each other for federal funding. The President's report should detail how individual science and technology programs fit into the Administration's overall strategy.

- **Forum for considering industrial technology needs.** No public policy forum exists where industry can discuss issues pertaining to technology and competitiveness. As a result, technology issues often do not receive a timely hearing, and policy responses often are implemented only after lengthy delays. The Assistant to the President should provide such a forum. It could take several forms, such as an advisory committee, an *ad hoc* group or a technology ombudsman. The form is secondary to the goal of ensuring that industry will have a high-level government forum where it can present its views on technology and international competition.

Rationalize the involvement of Congress in technology-related issues. The fragmented policy apparatus for science and technology extends to Congress. The systematic, long-term funding necessary for effective R&D is not adequately provided for by the competing demands facing Congressional appropriations committees or the current one-year federal R&D budget cycle. Three major issues deserve consideration: including technology issues in macroeconomic policy discussions, setting priorities and developing two-year funding for R&D.

- **Including technology issues in the discussion of macroeconomics policy.** The commercial application of technology is not a discrete issue, but an integral part of broader macroeconomic policy. Fiscal policy, savings rates, investment incentives and the cost of capital all have an important impact on the commercialization process. At present, technology issues are not carefully considered during critical macroeconomic policy junctures. Congress needs to focus more systematically on these issues.

- **Setting R&D funding priorities.** The Senate and House Budget Committees, in addition to setting overall funding priorities for various departments, should also review the entire federal R&D budget and outline R&D budget priorities. Such a review would recast the R&D budget debate away from the needs of individual agencies toward the R&D needs of the nation as a whole.

- **Two-year funding for R&D.** The President and Congress should work on a process whereby budget authorizations and appropriations for R&D both apply for two years. The cycle should begin with negotiations between the President and the Congress to establish a broad framework to guide the enactment of such a budget. This framework would be implemented under a two-year budget resolution, with the resulting allocations to the other congressional committees also binding for two years. To guarantee budgetary discipline, an enforcement mechanism would be established to keep the two-year appropriations within the limits established during the biannual presidential-congressional negotiations.

Make R&D tax provisions consistent over several years. Inconsistencies in U.S. tax provisions do not permit American industry to plan for R&D investments over the long-run. The R&D tax credit and Treasury Regulation 1.861-8 are examples of programs in which inconsistency has undermined industry's ability to plan for the future. The R&D tax credit should be made permanent and reviewed after 10 years to assess its impact on private sector investments in R&D. A permanent moratorium should be placed on the implementation of Treasury Regulation 1.861-8 to encourage the performance of R&D at home rather than abroad.

Increase funding for government agencies that contribute to the commercial application of technology. Although the Council supports reductions in the overall federal budget deficit, it is convinced that government support should be increased in areas that contribute to the ability of U.S. industry to commercialize new technology. These programs represent investments in future economic growth and their economic returns far exceed their immediate budget cost. Two government agencies stand out: the National Science Foundation and the National Bureau of Standards.

The National Science Foundation makes a critical contribution to the nation's science and technology base. Last year the Foundation's budget was $1.7 billion. In FY 1988, the President recommended doubling its budget over five years. So far, the necessary funding targets have not been met. National Science Foundation funding should be systematically increased to achieve the goal of doubling its budget by FY 1992.

The National Bureau of Standards is the primary federal laboratory with an explicit mission to aid U.S. industry. Because it is housed in the Department of Commerce, the Bureau often tends to be overlooked in R&D budget discussions. Systematic increases in its budget also should be supported.

Create a legal and regulatory environment more conducive to the commercial application of technology. Much of the current U.S. legal and regulatory system was established when the American economy was insulated from international competition. Reform is needed in three areas.

First, some, but not all, regulations are overly stringent and need to be eased. Not only do obsolete measures need to be reformed, but when new regulations are considered, more attention needs to be given to their potentially negative impact on the ability of industry to commercialize technology. Second, the U.S. regulatory process suffers from slow determination of standards and approval of new products. The standards-setting process is critical to the commercial application of technology and should be strengthened. For example, British companies are able to introduce new drugs to market more rapidly than U.S. companies because the United Kingdom approves new drugs much more expeditiously than the U.S. Food and Drug Administration. Third, the rationality of laws and regulations needs to be closely assessed. It is widely agreed, for example, that U.S. product-liability laws significantly hinder the commercialization of technology. These laws should be reviewed and reformed. In order to address issues in these three areas, U.S. regulatory agencies should make competitiveness an integral element of their missions. As part of this effort, better mechanisms to

analyze and coordinate the impact of regulation should be developed.

Legislative, administrative and private sector initiatives will be needed to accomplish these goals. Congress will need to reconsider specific statutes and may wish to add a general "technology mission" to all regulatory mandates (like the provision in the Toxic Substances Controls Act that directs the agency to avoid undue impacts on innovation).

In addition, agencies need to analyze more closely the impact of economic and social regulations on technology, making this focus more explicit under Executive Order 12291. In some cases, staff with more industry and technical experience need to be added to the regulatory agencies and to the Office of Information and Regulatory Affairs in the Office of Management and Budget. One reason for the Food and Drug Administration's delay in granting approval for new drugs, for example, is that it does not have adequate staff to meet the demands placed on the agency. Furthermore, the coordinating function across regulatory agencies needs to be strengthened to emphasize a new focus on technology. This function can be performed by the Office of Science and Technology Policy as well as the Office of Management and Budget.

RECOMMENDATION 3: THE FEDERAL GOVERNMENT SHOULD INCREASE ITS INVESTMENT IN THE EDUCATION, FACILITIES AND EQUIPMENT THAT CONSTITUTE THE NATION'S TECHNOLOGY INFRASTRUCTURE.

The federal government has a critical role to play in ensuring that the U.S. science and technology infrastructure is sound. Government programs contribute importantly to the education of scientists and engineers, the equipment and facilities, and the basic research that industry utilizes in its efforts to commercialize technology. Sustained investments in these areas are vital to the nation's economic future.

Make education, equipment and facilities a priority investment. In determining spending priorities, the federal government should follow three simple rules: first, it should make sure that there is adequate funding for science and engineering education; second, it should focus on investments in research equipment and facilities; and third, it should help fund projects in specific technical disciplines. Federal funding for "mega-science" projects, even if they are warranted on their own merits, have a much longer-term, indirect impact on U.S. competitiveness. To the degree possible, the United States should seek to work with other nations on mega-projects that relate to basic research.

Initiate a faculty-development program for science and engineering. Faculty development is one area in education that deserves special attention. There are approximately 1,300-1,800 vacant engineering faculty positions in U.S. colleges and universities, and some 60,000 math and science teachers in America's secondary schools are not fully qualified. There are also shortages of qualified science faculty. These shortages will increase in the early 1990s as faculty trained during the 1950s begin to retire.

Several innovative faculty-development programs have been put in place to remedy this situation, including the American Electronics Association's Fellowship Loan Program, Hewlett-Packard's Faculty Development Program and programs at the Society for Automotive Engineers. These private sector efforts, however, are not enough. In order to meet this shortage, the federal government should launch a major faculty-development program in science and engineering. Such a program should provide grants and loans to American citizens and permanent U.S. residents sincerely interested in teaching careers to enable them to pursue graduate-level studies. These loans could then be forgiven after three years of teaching.

A similar program could be designed for secondary science and math teachers, whereby federal grants and loans would be provided for graduate study and retraining, and forgiven after three years of teaching. The Education Directorate of the National Science Foundation should be responsible for managing the federal involvement in these programs.

Modernize university research facilities. A matching-grant program for increased federal and private sector investment in university research facilities should be established. Over the past 20 years, while many foreign competitors have been aggressively building up their R&D infrastructure, U.S. federal funding for university research plant

and facilities has declined by 95 percent in real terms. In a 1986 study on the health of U.S. colleges and universities, the White House Science Council estimated that a $10 billion program over the next 10 years would be required to bring U.S. university research facilities to an adequate level. The Council supports passage of legislation that would begin to provide the necessary funds.

RECOMMENDATION 4: THE FEDERAL GOVERNMENT SHOULD WIDEN THE FOCUS OF NATIONAL RESEARCH AND DEVELOPMENT EFFORTS.

Recent federal technology initiatives have concentrated on cooperative R&D. Some efforts, such as technology transfer, have focused on links between national labs and industry; others, such as Sematech and the National Center for Manufacturing Sciences, have focused on the need to sponsor more cooperative R&D and generic manufacturing among different companies in the same industry; and still others, such as the National Science Foundation's Engineering Research Centers, have focused on the need to conduct multidisciplinary research among different sectors of the economy. Although it is still too early to draw definite conclusions from these programs, it is clear that the federal effort to promote cooperative R&D among industry, universities and government should be expanded and that more resources should be directed toward R&D that is relevant to the private sector.

Re-evaluate the agenda and purposes of the federal laboratories and their relationship with industry. There is no consensus on the scope, mission and relevance of the federal laboratories to the needs of the nation over the next 20 years. Their role and utility should be thoroughly re-examined. Although the Council has not undertaken such an examination, much of U.S. industry agrees that the laboratories need to be streamlined: some need to be consolidated and others need to be closed. At minimum, technology transfer should be elevated to an important criterion in evaluating lab performance. The exchange of technical personnel between the labs and industry should be encouraged as part of this effort.

Facilitate cooperative generic manufacturing technology. The federal effort to facilitate cooperative R&D among industry, universities and government should be encouraged. This framework is effective for generating concentrated, long-term funding and an excellent pool of talent. It remains uncertain, however, whether a significant number of participating companies will make speedy use of the results. A priority consideration in establishing cooperative R&D efforts should be active participation by industry, a focus on base-building technologies and processes rather than products, and the rapid transfer of new knowledge from the laboratory to the marketplace. Such efforts as Sematech and the National Center for Manufacturing Sciences recognize that the private and public sectors have to find new ways of working together if American industry is to respond to the reality of global competition. These efforts should be evaluated carefully to assess how best to structure joint approaches to problems involving generic manufacturing.

Improve federal coordination with state technology programs. During the 1980s, state technology-support programs have proliferated, matured and, in some cases, been remarkably successful. The states have filled a niche for which the federal government is ill-equipped: small-scale, grass-roots efforts involving local businesses, universities and government that focus on the application of technology. At the very least, the federal government should be careful to coordinate its science and technology programs with state efforts. Some state administrators, for example, are concerned that the National Science Foundation's interdisciplinary centers might duplicate existing state-organized centers of excellence.

The first step in improving federal coordination with the states is to create a better information base about state technology programs. The Bumpers provision to the omnibus trade bill would help accomplish this goal. It would establish within the Department of Commerce a clearinghouse for state and local initiatives related to the promotion of technology. The clearinghouse would collect and disseminate information on federal, state and local initiatives, and develop methodologies that state and local governments could use to evaluate their programs. It also would provide technical

assistance and advice about these initiatives. This program should be implemented fully.

Encourage Department of Defense efforts to strengthen the U.S. industrial base. The Department of Defense has a vital interest in the health of the U.S. industrial base. In times of national security crisis, it must be able to rely on a strong and diverse national industrial capacity. With pressures on the federal budget, the United States is unlikely to achieve the scale and scope of funding support for science and technology that is relevant to the needs of American industry unless the Pentagon is involved. The Department of Defense should use its procurement policy and R&D budget to strengthen the U.S. industrial base. Its efforts are likely to be most constructive when they focus on conducting critical basic research, developing key technologies and improving production processes, rather than on indentifying and supporting specific industries or industrial products.

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Founded in 1986, the Council on Competitiveness is an organization of leading executives from industry, organized labor and higher education who have one overriding objective: to improve the ability of American companies and workers to compete in world markets. Among the Council's more specific goals are to increase public awareness of the competitiveness challenge; to promote consensus and cooperation on competitiveness-related issues within the private sector; and to assist in the development of far-sighted government policies that help Americans compete.

The Council is governed by an executive committee and draws on the resources of its national affiliates — more than two dozen trade associations, professional societies and research organizations — to help coordinate private sector activity. The Council is privately supported through contributions from its members, foundations and other granting institutions.

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